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PRODUCER GAS FIRED FURNACES

DETAILED DESCRIPTIONS AND ILLUSTRATIONS OF PRACTICAL PRODUCER GAS-FIRED FURNACES OF THE CHEMICAL, METAL, METALLURGICAL, IRON, STEEL, LIME, CEMENT, GLASS, BRICK AND CERAMIC INDUSTRIES. A HANDBOOK FOR ENGINEERS, CHEMISTS, MANUFACTURERS, SUPERINTENDENTS AND STUDENTS

BY

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With 237 Illustrations

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PREFACE.

The use of producer gas as an industrial fuel increases constantly and represents a progress in economy and hygienics. One ton of coal will do more work after its transformation into gas—as compared to direct firing—the hygienic advantage involved therein being the smokeless combustion of the gas. Furthermore, high grade coals can be replaced by low grade fuels, if the solid combustibles are gasified before being burned.

The suitable construction of the industrial furnace is of the greatest importance for the satisfactory application of producer gas. To give detailed descriptions and practical illustrations of nearly all kinds of gas-fired furnaces is the main object of this book, which is the first American work on this subject. Actual installations of the furnaces used in the chemical, metal, metallurgical, iron, steel, lime, cement, glass, brick and ceramic industries are described and illustrated. The combustion of producer gas and the construction of producers are also treated with sufficient detail.

The author feels certain that this book will be of value to engineers, chemists, manufacturers, superintendents and students, and he hopes that by this publication industrial improvements will be hastened, which will be of equal benefit to the nation, to the manufacturer and to the workingman.

OSKAR NAGEL, PH.D.

NEW YORK, November, 1909.

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CHAPTER I.

THE GENERATION OF PRODUCER GAS.

The producer is a simple and efficient apparatus for the manufacture of a cheap industrial gas. Other important advantages of this apparatus and its application are: smokeless combustion of great uniformity, exact regulability of the fire and heat, and the attainment of very high temperatures by preheating the air of gasification and combustion. By working with an excess of air or gas, respectively, an oxidizing or reducing flame is produced. Finally the combination of the various fireplaces into one central station and the saving effected in the cost of transportation of fuel and ashes are factors which should by no means be underestimated.

Our solid fuels contain besides the free carbon also carbon which is combined with hydrogen and oxygen. These compounds form the bituminous or volatile components of the fuels. They amount in wood up to 82 per cent. of the total combustible matter; in peat to 60 to 65 per cent.; in lignite to 55 per cent.; in bituminous coal to 45 per cent. or less, and in anthracite to 5 per cent. or less.

If fuel is heated under exclusion of air, the volatile matters are separated, *i. e.*, the coal is being "degasified." In this process hydrocarbons, hydrogen and also carbon monoxide, carbon dioxide and water are formed. The latter increases with the moisture content of the fuel and escapes during the destructive distillation (degasification). The residue—pure carbon and ash—is called coke, charcoal or peat coal.

If the destructive distillation is carried on at high temperature, as, for instance, in gas works and coking plants, a strongly illuminating gas and liquid tar are formed. At low temperatures the quantity of hydrocarbons is larger, the illuminating gas and hydrogen decrease considerably, the tar gets thick, and, with lignite and peat, also paraffine is produced. The destructive distillation at low temperature also occurs—to the disgust of the manufacturers—in the generation of producer gas.

The generation of producer gas is based upon "gasification," *i. e.*, the transformation of the free carbon of the fuel into carbon

monoxide, and it is easily understood that for this process a fuel containing the largest amount of carbon and the smallest amount of volatile matters will be most desirable. Such fuels as anthracite, charcoal and coke, however, though easily transformed into a gas free of tar, are too expensive to be used in the big industries, which are forced to use bituminous coal, wood and lignite.

In small producer plants, especially in connection with gas-power plants, the higher price of anthracite is outweighed by its greater convenience. But even here conditions are changing and the use of bituminous fuels is being slowly but surely introduced.

The gasification of the carbon in the producer is effected in such a manner that the carbon is first burned to carbon dioxide, the latter being then reduced to carbon monoxide by contact with additional carbon. Hence, carbon monoxide is the essential component of producer gas.

The perfect reduction of dioxide to monoxide takes place, theoretically, at a minimum temperature of 2000° F., which is easily produced by combustion to carbon dioxide. At lower temperatures part of the dioxide is not reduced, the formation of the monoxide stopping entirely at about 840° F.

In order to effect the reduction, a high fuel bed is used and less air admitted than would be necessary for complete combustion. The formation of carbon monoxide caused by too high a layer of fuel is of frequent occurrence in ordinary fireplaces and means a considerable loss. It is also known that in direct firing a considerable excess of air has to be admitted if the formation of carbon monoxide is to be avoided.

The height of the fuel bed in producers necessary for complete reduction varies with the quality of the fuels used. Dusty fuels require less height than coarse, loose, fuels. The proper height for 1-in. coke is 30 in.; for 1½-in. coke, 45-in.; for 2¼-in. coke, 72 in.; for ¾-in. bituminous coal, 22 in. are sufficient; for run of mine, 60 in. to 80 in.

This fact shows that it is of advantage to use fuel of uniform size in the producer. Coarse pieces of dust interfere with the uniformity of the gas production and allow the formation of holes, *i. e.*, vertical channels in the fuel bed, so that a part of the air admitted to the producer goes through unchanged, simply deteriorating the gas. However, the low price of run-of-mine coal neces-

sitates its application in industrial gas producers whereby the prevention of hole-formation by means of poking becomes imperative.

With bituminous fuels too high a fuel layer is not to be used, as this causes an increased formation of tar and soot, for the volatile matters and the moisture escape from the higher zones before the fuel reaches the incandescent zone of reduction. The higher the temperature of the upper layers, the thinner will be the tar produced and the more hydrogen and methane will be found in the gas. The two latter components increase the thermal efficiency, but the tar, together with the soot, is a disagreeable impurity of the gas, more so if the gas is cooled before its use.

This is always the case where the producers are not built right at the furnaces in which the gas is to be burned. On the other hand the separation of the tar, which has a certain thermal efficiency, and the cooling of the gas involve always a loss. Experiments have lately been made to utilize the tarry components of the producer gas or to decrease the quantity of tar formed. It is known that tar, if drawn through incandescent coal, is transformed into permanent gases (hydrogen, methane, etc.).

As stated above, a temperature of not less than 2000° F. is required for complete formation of carbon monoxide. If considerably higher temperatures are applied, the disadvantages will be found to outweigh the advantages, as by such high temperatures the fire-brick lining is rapidly destroyed and the ashes of the fuel always obtained as molten slag.

Such slag formations occur with various grades of fuels, depending upon the composition of the ash, at higher or lower temperatures. In the latter case it can only be avoided at the expense of the gas production. Here the addition of water to the gasifying air is a simple remedy, which, at the same time, increases the thermal value of the gas and the efficiency of the producer, simultaneously cooling the grates of the producer.

Incandescent coal decomposes water into its elements. The hydrogen formed enriches the gas and the oxygen combines with the carbon to carbon dioxide or monoxide according to the prevailing temperature. The formation of monoxide by the decomposition of water is most complete at a temperature of 2000° F., while at lower temperatures more and more carbon dioxide is produced. In practice, however, it is impossible to decompose all the

water contained in the gasifying air. One part goes always unchanged through the producer and increases the moisture content of the gas. If this moisture is present in the gas during its combustion it has a heat-consuming effect and decreases the temperature of combustion.

Hence, no water is to be added for the gasification of fuels rich in water, and some fuels require even drying, if with the gas produced a somewhat high temperature is to be reached. It is also evident that the temperature of the gas leaving the producer decreases with the temperature of the producer and with the increasing amount of heat which is disposible for degasification and evaporation.

If, for instance, in the gasification of dry bituminous coal the temperature of the gas leaving the producer is 1100° F. to 1400° F., a temperature of only 800° F. to 900° F. will be observed if water is added. This shows that by addition of water less heat is lost by the cooling of the gases, the loss by radiation being also simultaneously decreased.

Of great importance is the question: How much water may be advantageously added? Fuels with a large percentage of volatile matters can stand only a small addition of water, as, already during their degasification, much water is formed; *i. e.,* much heat is lost. If such fuel is also very moist the result may be a non-combustible fuel gas, if the gas is not dried before being used by cooling, whereby a large part of the water may be removed by condensation.

The amount of water added must be regulated so that the walls of the producer do not suffer by the heat and that, as much as possible, the formation of liquid slag is avoided.

In gasifying pure carbon 1 lb. of water may be added to 70 cb. ft. of cold gasifying air without causing any loss of heat and as for gasifying 1 lb. of carbon about 70 cb. ft. of air are required, the upper limit of the addition of water is about 1 lb. to 1 lb. of carbon.

If the air of combustion and the water added are preheated the quantity of the latter may be increased and may reach at 1000° F. double the amount mentioned above. This explains why in practical gasification of coke, which is practically pure carbon, ¾ to $\frac{9}{10}$ lb. of water are added per 35 cb. ft. of air if a gas rich in hydrogen is to be produced.

In gasifying bituminous coal for the production of a gas not too rich in hydrogen, ⅜ lb. of water are taken per 35 cb. ft. of air. From a theoretical point of view, however, a somewhat larger addition of water is nearly harmless, so far as the utilization of the fuel is concerned. It is true that in such a case a larger quantity of carbon dioxide will remain unreduced, but with the increased quantity of decomposed water, also more pure oxygen will get into the producer. Hence, less gasifying air is required, which means a decrease of the nitrogen content of the gas produced.

The composition of producer gas is varying a great deal. Under normal conditions, if a good grade of fuel is used and the operation properly carried out, the gas will contain about 25 per cent. of carbon monoxide. If the producer gets very hot, by the total or nearly total absence of water, the content on carbon monoxide may be up to 30–31 per cent.

The second combustible component of producer gas is hydrogen, varying in quantity between 8 to 14 per cent. However, the hydrogen content may be even higher or lower, depending upon the moisture of the gasifying air and other conditions. Some factory managers are afraid of too high a content on hydrogen and believe that it does harm to the firebrick and affects the finished product disadvantageously.

So far, however, continued operations with producer gas from peat, which is rich in hydrogen, have been and are being carried out successfully; the harm—if any—done must be due to some other cause, probably to the moisture of the gas, which causes decomposition of and recomposition to water, thereby effecting numerous disagreeable complications. Accordingly a gas rich in hydrogen would have to behave differently when cooled (dried) before its use or when used hot.

That the hydrogen cannot be the only cause of the above-mentioned complications (sudden rise of temperature) is shown by the fact that carbon monoxide in combustion, though not yielding as many thermal units as hydrogen, produces a higher temperature. Hence, a gas, which on account of its high content on hydrogen, has a higher thermal value as compared with others, may be equivalent to the latter, as far as the temperature of combustion is concerned.

There is a certain relation between the percentage of carbon

dioxide and the percentage of carbon monoxide and hydrogen. That it is not always of advantage to get a gas with the lowest possible content of carbon dioxide we can see from the fact that at dry gasification, where very little dioxide is formed, the efficiency of the producer is much lower, as with a large addition of water.

On the other hand, the content on dioxide is also influenced by the nature of the fuel, as with low melting slag the temperature must be kept so low that the complete transformation of dioxide into monoxide is prevented. Some grades of coal, therefore, will only difficultly be gasified at reasonable economy if the formation of slag is not taken into consideration and if the producers are not constructed to suit these conditions. As a rule the carbon dioxide should not go above 3 or 4 per cent.

The methane gets into the producer gas from the products of decomposition of the volatile matters. The quantity of methane varies from 1 to 3 per cent. and depends upon the temperature of degasification. The heavier hydrocarbons are also sometimes found in traces if the temperature of degasification is very high.

If the tarry compounds of the gas are decomposed in the producer, the composition of the gas is changed, the percentage of carbon dioxide and hydrogen is decreased, of the monoxide increased. As the hydrocarbons have a high thermal value their presence is desirable, especially if high temperatures are to be reached.

Some oxygen is also generally present in producer gas. Leaks and holes in the fire are mostly the causes of its presence. The rest of the gas is nitrogen, which, at dry gasification amounts to 60 per cent., at moist gasification to about 50 per cent.

CHAPTER II.

THE CONSTRUCTION OF GAS PRODUCERS.

We distinguish two fundamental types of producers.

The first and oldest has been developed from the blast furnace and is a vertical shaft in which the fuel moves downward, while the air and the gas travel in the opposite way. The gas formed passes through the green fuel, carrying along water and volatile matters. The shaft is built of firebricks and surrounded by a wrought-iron shell. The tops of the producers are sometimes made of an arch of firebricks, but frequently only provided with water-cooled covers made of iron. Cast steel is also sometimes used for the parts that are exposed to considerable heat. The shaft is generally circular, sometimes, however, square. The walls are mostly vertical, sometimes showing wider and narrower portions, as will be seen from the illustrations.

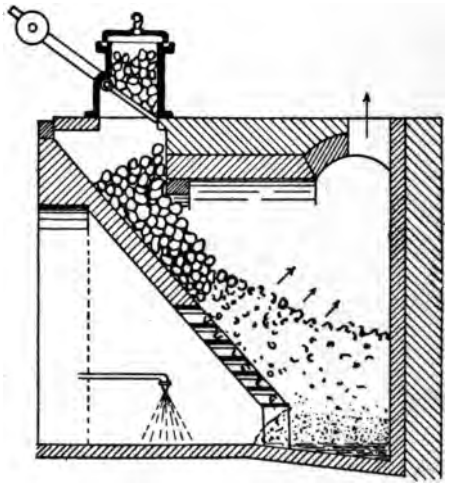


FIG. 1. SIEMENS PRODUCER.

Fixed rules as to the interior shape cannot be given, different fuels requiring a different treatment. The main consideration must be to provide for the increase of volume of certain coals during the period of distillation; for this reason the shaft is enlarged down to the zone of reduction. The walls near this zone should be vertical so as to prevent, as far as possible, the slag from sticking. At the bottom end the shaft is frequently made narrower in order to force the air straight upward, instead of along the side walls. Such a narrowing will never do any harm, as at this point the volume of the fuel is already considerably decreased by the partial combustion. Vertical walls facilitate the uniform downward travel of fuel.

Poke holes are generally provided in the cover and in the side walls, in order to make it possible for the fireman to reach the interior layers of the fuel and to break up the clinker.

Since in a vertical shaft the fuel is easily kept at uniform height, the shaft producer is used to-day *almost* exclusively, but *always* in cases where the producer plant is not directly connected to the furnace.

The second type, which was developed by Siemens, is used when producer and furnace are built in one unit (Fig. 1). The fuel is charged through a hopper provided at the top and passes over an inclined firebrick wall, which, at the bottom, is continued as a step-grate.

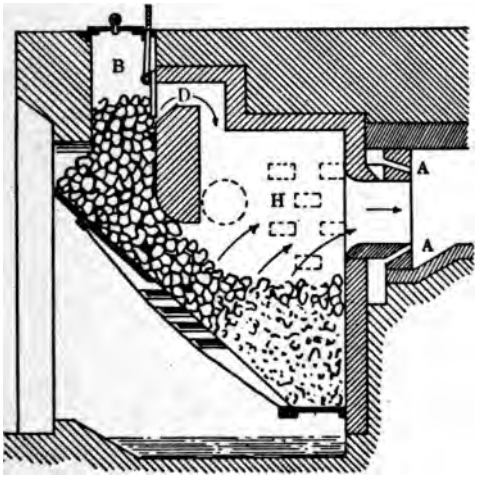


FIG. 2. "HALF-GAS FIRING."

The Siemens type of producer offers less resistance to the passage of the gas through the fuel bed than the shaft type, as in the latter the gas has to travel through the entire height of the coal contained in the producer. For this reason blowers are used in producers of the shaft type, while in Siemens producers in many cases natural draft, produced by a stack behind the furnace, is employed; this, however, frequently necessitates a reduction of the fuel layer and thereby causes incomplete gasification.

The loss produced by the last-mentioned fact is not very considerable as the gas produced is directly and immediately used and pretty nearly all the heat passing from the producer to the furnace utilized. If, on the other hand, the gas would be cooled before being used, very considerable losses (up to 40 per cent. or 50 per cent.) would result. Therefore, shortly after the introduction of the Siemens producers addition of water was employed by arranging a water pan in the ash pit and producing the steam by the radiating heat.

Within the class of Siemens producers we must also include the

so-called "half-gas firings," which are especially used for low-grade fuels. These firings are not supposed to produce complete gasification. The gas produced contains much carbon dioxide. For utilizing the monoxide, an additional supply of air is introduced in the combustion place.

In the charging hopper *B* (Fig. 2) tarry gases and steam are produced by dry distillation. In order to prevent them from escaping during the charging of fuel, connecting channels *D* are provided between the producer *H* and the hopper. These channels are frequently provided with a movable slide. The secondary combustion air enters through tuyeres *A* after being preheated in the brick-

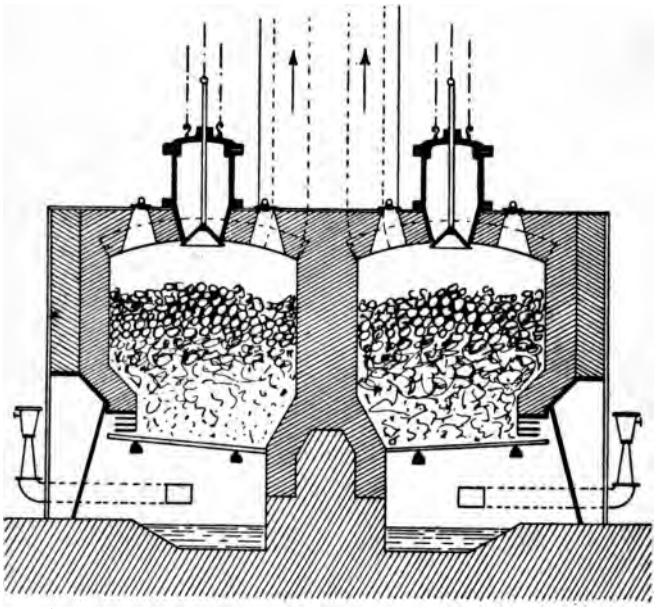


FIG. 3. MODIFIED SIEMENS PRODUCER.

work. It is a disadvantage that these producers depend on the chimney draft, because the latter is governed by atmospheric conditions. Hence, even in these producers artificial blast has been resorted to, which permits the use of a higher fuel bed. Fig. 3 shows this new development of the Siemens producer (four producers combined to one unit), which is very similar to the shaft type.

The use of an artificial blast for producers is almost universal for heating purposes; however, considering the generation of power

we find an exception in the so-called suction-gas producer plants. Here the sucking power of the piston of the gas engine is utilized for drawing the air through the producer, the quality of gas produced being automatically regulated by the demand of the engine. As the sucking power of the latter is very large, the difficulties met with in producers with natural draft do not arise in this case.

The aim in the development of the construction of modern producers is the reduction of manual work, the production of a uniformly good gas with high efficiency, and, if possible, by a continuous operation of the producer.

The latter point is especially desirable with installations containing only one producer, while in plants comprising a number of producers an alternate disconnection for cleaning purposes is possible. If one main is supplied from several producers, the uniformity of the gas is increased.

The charging appliances of gas producers must be so arranged that the production of gas is not interfered with during the operation of charging. Hence, in producers of the draft and suction type the entrance of air has to be prevented; in pressure producers the escape of gas. This is effected by bell hoppers.

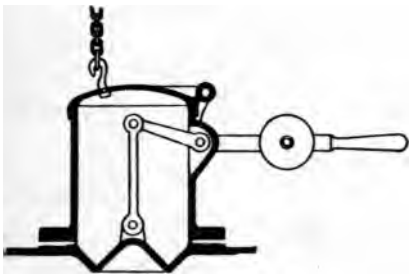


FIG. 4. HOPPER.

In all these hoppers the fuel to be charged is first transported to a hopper space, which is separated from the producer space proper by an air-tight bell. Then the upper door of the hopper space is closed and by opening the bell the charge is allowed to run into the producer. Fig. 4 shows such a hopper. The charging is done at certain intervals, which causes a change in the uniformity of the gas, as the dry distillation of the green coal is not going on uniformly. *Wendt* observed changes of more than 10 per cent. in the thermal value of the gas when working with a producer charged with coal rich in gas. The harder the fuel, the smaller are the variations.

In order to produce a more uniform gas and to reduce the manual work, continuous charging has been tried by various ways.

The first, suggested by Ebelman, Fig. 5, in the first half of the

nineteenth century, consists of the application of a charging shaft, from which the fuel gradually travels to the zone of combustion. The gas is drawn off outside the charging shaft whereby the latter assumes the temperature of the escaping gas. This causes the generation of gas already in the shaft and makes the use of a bell hopper (Fig. 4) unavoidable, except in cases where still larger quantities of fuel are kept in readiness above the charging shaft. The latter is generally made of cast iron, and is gradually destroyed if exposed to high temperatures.

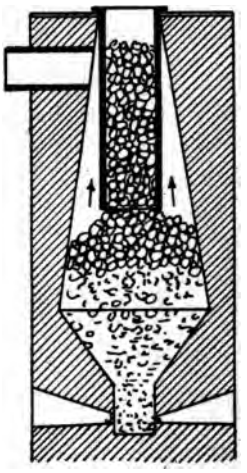


FIG. 5. EBELMAN METHOD.

In the producer of Buire-Lencauchez (Fig. 6) the gases escape through the charging shaft.

In the producer of Bleringer the fuel is charged outside around the central pipe, which serves only as escape for the gas.

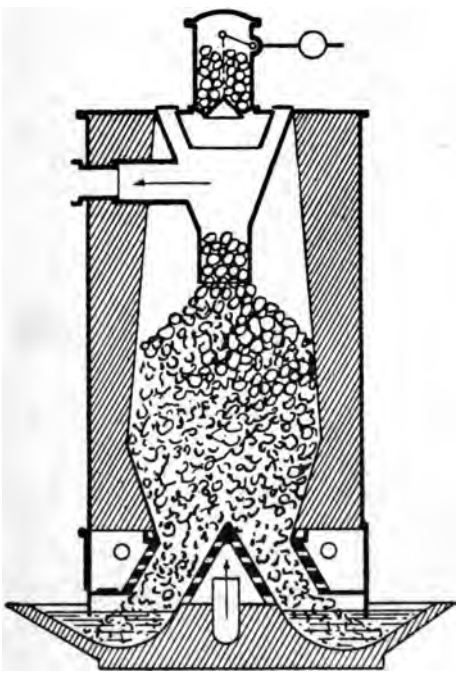


FIG. 6. BUIRE-LENCAUCHEZ PRODUCER.

Zetzsche has gone still further (Fig. 7) by so developing this central pipe that it can be lengthened or shortened, whereby the height of the fuel bed can be regulated according to the quality of the fuel. The lower rings of the pipe can be easily exchanged if necessary.

A second method of charging continuously employs various mechanical appliances, the first among them having been constructed by Bildt (Fig. 8). A water-seal producer with Bildt feed is shown in Fig. 9.

To-day there is a considerable number of mechanical charging devices on the market. The Morgan feeder, of the Morgan Con-

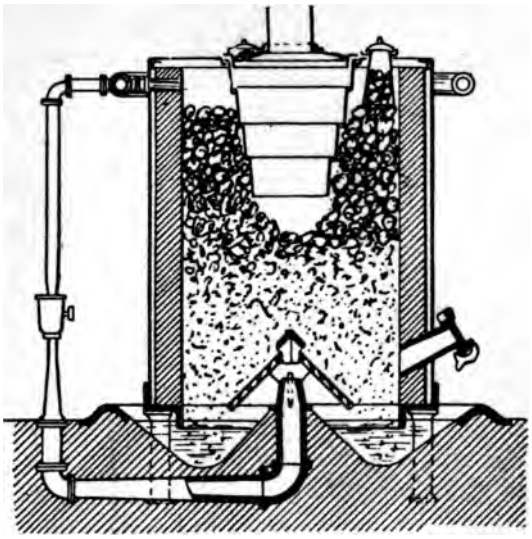


FIG. 7. ZETZSCHE PRODUCER.

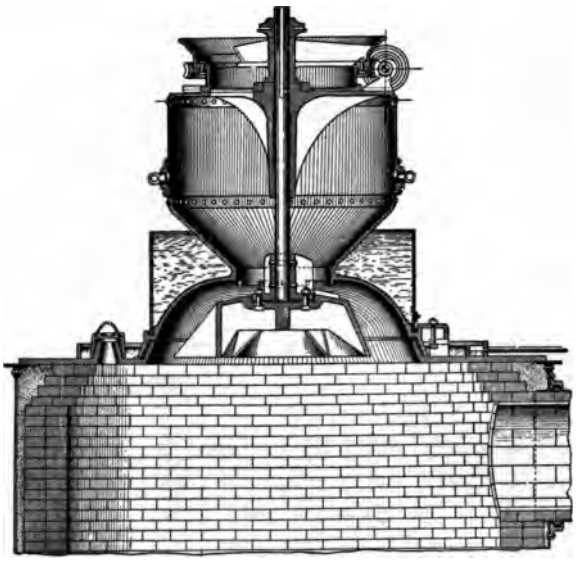


FIG. 8. BILDT FEED.

struction Company, of this country, the automatic feed of which is stated to insure almost absolute uniformity of both quantity and

quality of gas produced, is shown in Figs. 10 and 20; the feeders of Poetter & Company in Figs. 11 and 12.

The Poetter producer is not provided with a bell hopper. However, it is recommended to make an air-tight pipe connection from the hopper to the coal storage. By opening a slide the desired

FIG. 9. WATER-SEAL PRODUCER, WITH BILDT FEED.

quantity of fuel is allowed to run into the hopper. This feed can also be made absolutely mechanical. Those parts of the feed which come in contact with the hot gases are generally water cooled. A distributor takes care of the uniform distribution of the fuel. This feature makes these constructions superior to the plain bell hoppers. However, the mechanical feed is used only for large units.

While with all producers it is of advantage to use a fuel of uniform size, this is especially important in producers which are charged mechanically. Poetter has constructed a feed for coarse coal in which he provides a crusher above the distributor.

FIG. 10. MORGAN PRODUCER.

It must not be overlooked, however, that considerable quantities of dust are produced by the action of these crushers. This causes an increase of the impurities of the gas, a tight packing of the fuel and finally the formation of holes.

A charging device for Russian wood producers is shown in Fig. 13.

Another important part of the producer is the means for removing the ash and clinker. Here the aim is also to reduce the manual

work and to decrease the loss of combustibles through the ash. In the old Siemens producers up to 10 per cent. of the fuel was found

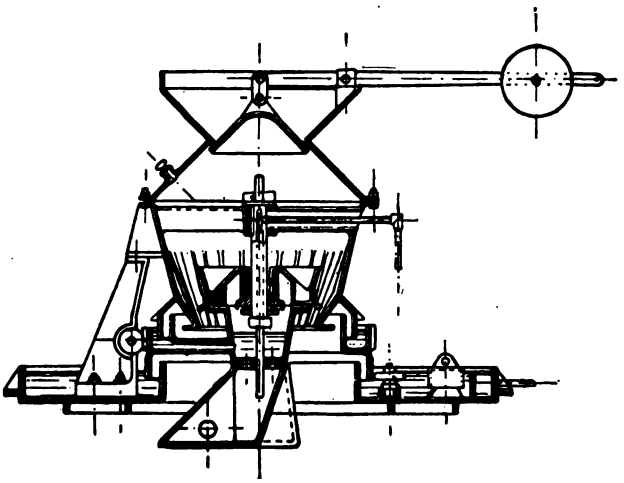


FIG. 11. POETTER PRODUCER.

in the ash, later producers showed a loss of 5 per cent., while in modern producers the loss is said to be reduced to 1 per cent. or 1.5

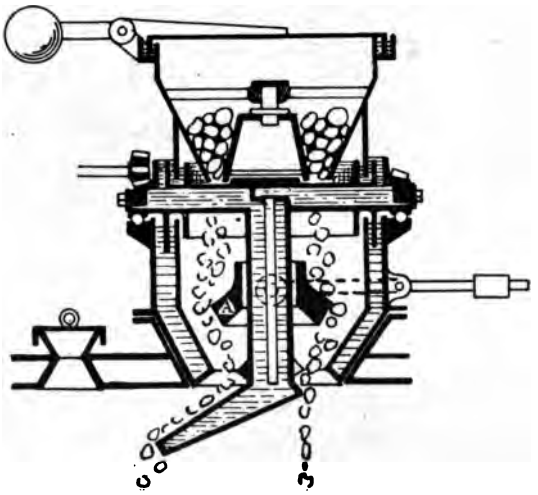


FIG. 12. POETTER PRODUCER.

per cent. Further aims are the removal of clinker without discontinuing the operation of the producer and accessibility of its respective parts.

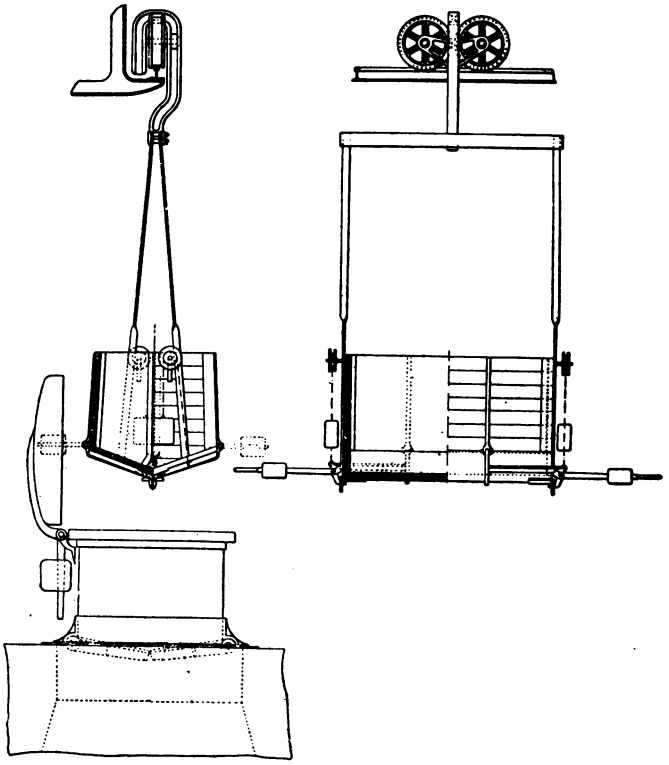


FIG. 13. CHARGING DEVICE FOR RUSSIAN WOOD PRODUCERS.

We will now say a few words regarding the blast, which is produced in all, or nearly all, plants by means of steam jet blowers, which are the most convenient appliances to that end, as they do not get out of order; furthermore, every producer is, and remains, independent with respect to the blast if the latter is produced by steam jet blowers. (For very wet fuels, as certain grades of peat and lignite, dry blast has to be used, as is easily understood.) The steam jet blower must be properly constructed in order to produce economically the highest possible steam velocity.

Fig. 14 shows the well-known Koerting blower with spindle. *A* is the air inlet, *R* the regulating spindle, *S* the steam connection, *M* the nozzles. With ordinary bituminous or hard coals there is no difficulty to so regulate the quantity of air by means of the steam jet blower as to get dry gas. It is hardly necessary to lay stress upon the self-evident fact that the steam used in these blowers should be dry.

A high-pressure blast is of no advantage in the operation of producers, as it means an unnecessary loss of energy, formation of holes and deterioration of the gas.

Returning again to the discussion of the ash-pit region, we show in Fig. 15 the ash pit of a producer without a grate. The ash rests upon a firebrack base, the air enters through the sides as shown by the arrows. In a vertical producer of considerable diameter the air will rise along the wall, the path of least resistance, whereby a dead zone is formed in the center of the shaft, causing a defective production of gas. Therefore, in large producers the diameter is frequently decreased toward the bottom. The simple plane grate insures a uniform distribution of the air over the entire area. However, with large diameters the life of the grate is short and the removing of the clinkers a very tedious and difficult operation. Furthermore, the unburned fuel falling through these grate bars represents a considerable loss.

FIG. 14. KOERTING BLOWER.

For facilitating the removing of the clinkers in large producers, so-called "false grates" have been resorted to, which at the period of cleansing are inserted above the ashes. In this case the gas production is stopped during cleaning. Turk's producer, which is illustrated in Fig. 16, shows in slit *e* the place where the false grate is inserted above the grate *h*.

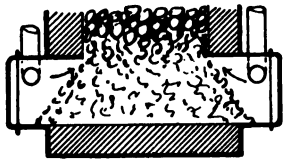


FIG. 15. ASH-PIT.

Step grates are also sometimes employed. Fig. 17 shows such an arrangement in a Turk producer. Fig. 18 illustrates a Poetter producer with so-called polygonal grate. The removal of the

clinker from these producers is by no means an easy job. The loss through fuel getting into the ash is 5 per cent. to 6 per cent.

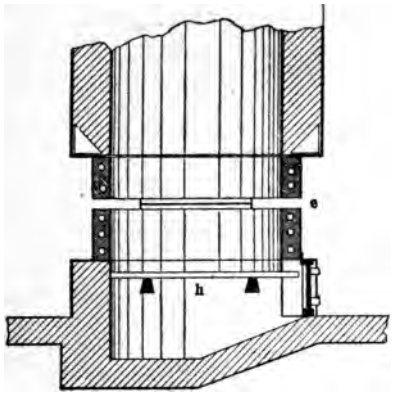


FIG. 16. TURK'S PRODUCER.

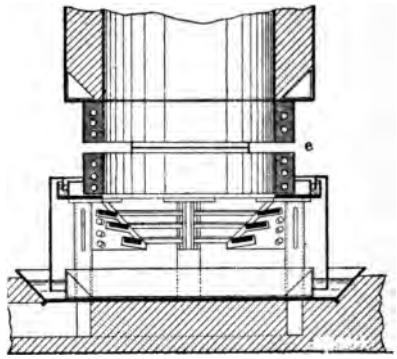


FIG. 17. TURK'S PRODUCER.

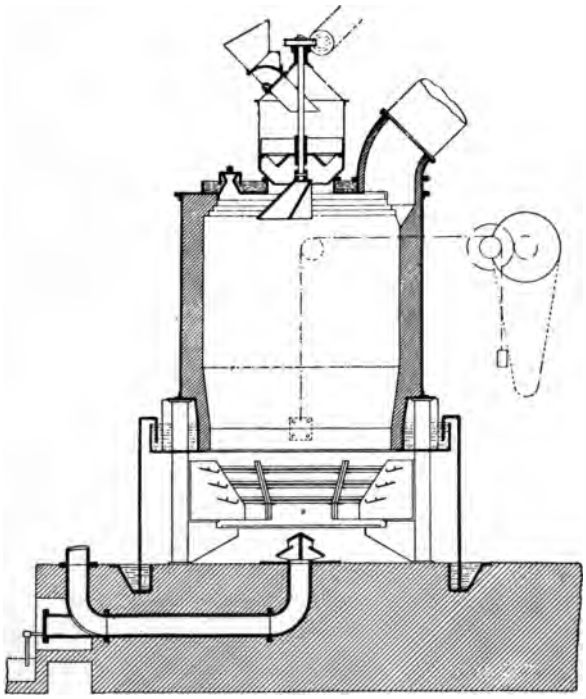


FIG. 18. POETTER PRODUCER.

Of similar construction is the producer with basket-shaped grate, which is built by Paul Schmidt and Desgras. It is mainly used

for lignite briquettes. The channels for the admission of air also support the circular lower grate beam. The ashes rest in most of these constructions upon the bottom of the ash pit, which is cov-

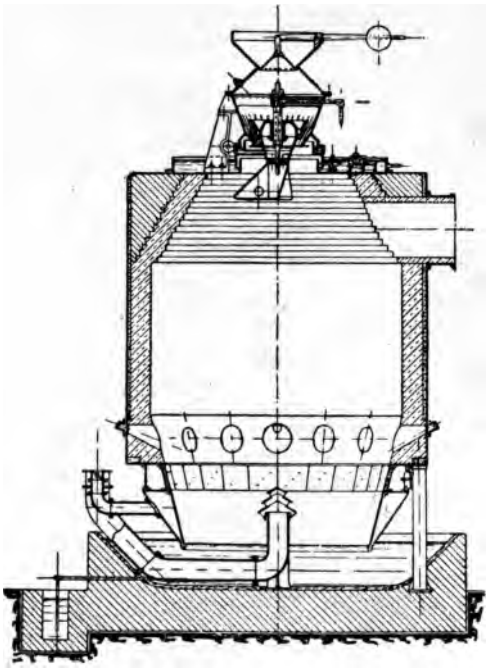


FIG. 19. PRODUCER, WITH WATER SEAL.

ered with water. Sometimes also plane grates are used at the lowest point of the grate region. The Mond producer shows a similar construction around the grate.

In all these producers the clinker accumulations formed must be loosened through the grate slits. Hence the various parts have to be removable and exchangeable In order to facilitate the removal of the clinkers, Schneefuss has proposed a shaking grate of basket shape suspended on chains.

During the period of removing the clinkers, the operation must be interrupted in all these producers, as the ash doors have to be opened.

If the operation of the producers is to be continuous, the ashes and clinkers must be removed during the operation. This is effected either by a water-seal or by mechanical draft appliances. A

typical producer with water seal as constructed by Poetter & Company is shown in Fig. 19. The combustion air is introduced through a central pipe. The hot bed of ashes effects a posterior combustion of carbon particles which might have escaped combustion and causes a better distribution of the air.

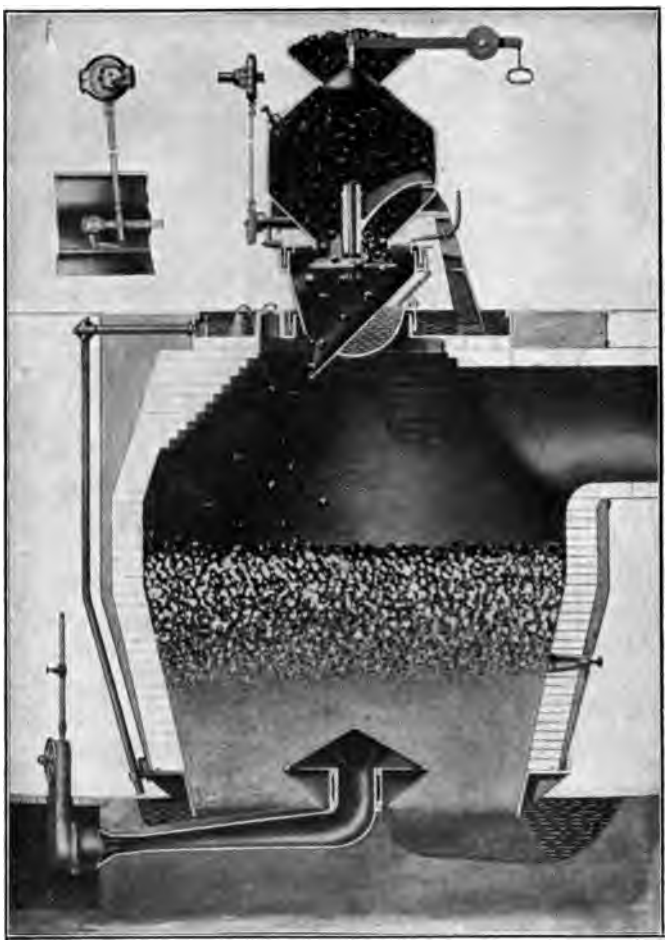


FIG. 20. MORGAN PRODUCER.

In the Morgan producer (Fig. 20), which gives excellent results —the loss of fuel in the ash being reduced to 1 per cent. to 1.5 per cent.—the air is introduced in the center, while Schlueter (Fig. 21) arrives at good results by introducing air at the sides through

a certain number of tuyeres and by suitably reducing the diameter of the producer in the zone of combustion.

As part of the water of the seal is evaporated by the heat of the ash, the quantity of water (steam) put into these producers must be reduced. The clinkers are loosened through poke holes in the walls. A producer of remarkable simplicity in which the removal of ash and clinkers is easily performed is the Duff producer, which in the Bradley modification is shown in Fig. 22.

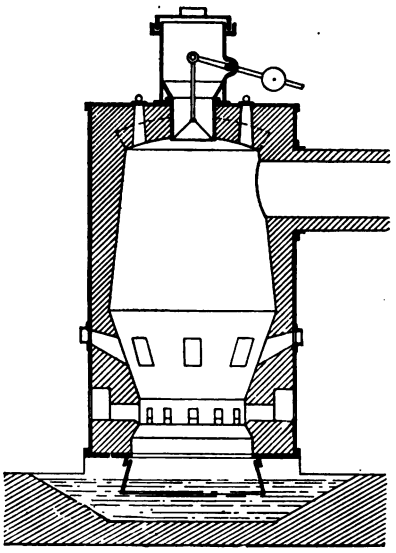


FIG. 21. SCHLUETER PRODUCER.

The special feature of this producer is the use of four blowers and four grates. It is to be stated that, while only two grates are shown in the cut, a dividing plate is provided between each grate. This makes practically four independent grates. For instance, should the fire get too hot at either of the end walls running parallel with the grate, the blowers controlling those halves of the grates

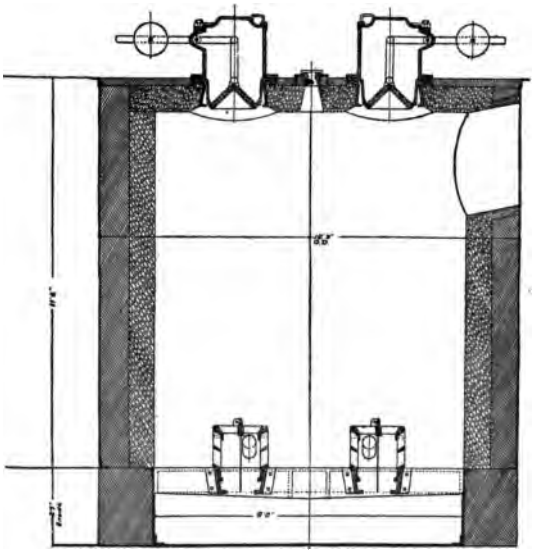


FIG. 22. BRADLEY-DUFF PRODUCER.

are closed down partly or entirely, as the case may require. This applies also to the center halves of the grates, which are controlled and regulated in the same manner. Hence, an excellent control of the condition of the fire is effected by the regulation of the steam and air blast.

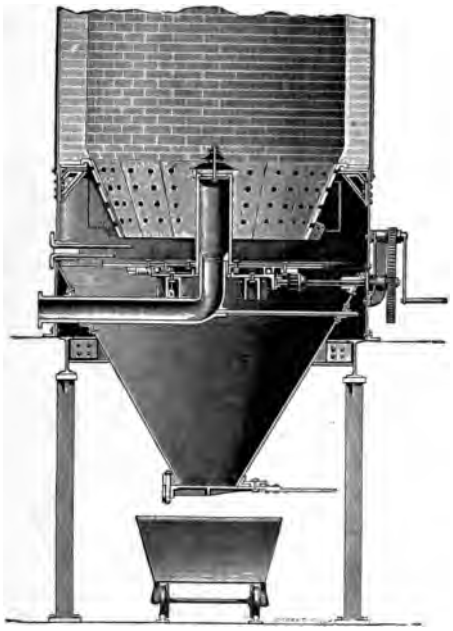


FIG. 23. TAYLOR PRODUCER.

For the removal of ashes mechanical arrangements have also been constructed. The Taylor producer (Fig. 23) was among the first of this kind. In this type a solid circular bottom plate or table carries a deep bed of ashes and is arranged to revolve; the revolving of this table discharges the ash and clinker over the edge into a sealed ash pit beneath. The table is revolved by means of a rack under the table, engaging with a pinion on a shaft driven by hand or power gearing substantially attached to the outside of the lower casing. Suitable guides hold the table carefully. The grinding is done as fast as the ashes rise too far above the desired line—say, every six to twenty-four hours, or according to the rate of working. The bed of ash is kept about 3½ ft. deep on the revolving table in the larger size.

Another example of a self-cleaning continuous producer is the Hughes type, shown in Fig. 24. This producer is divided into two parts, the upper and the lower, with a water seal between, the upper portion rotating mechanically. By means of an iron bar, thrust between the ash table and the revolving part of the body, the clinkers are broken up and with the ashes fall into the ash receptacle beneath. By opening an outlet valve at the bottom of this cone-shaped ash receptacle the ashes are discharged into cars underneath.

The upper shell of the producer is made of steel plate riveted to and resting upon a steel ring forming a combined tread and rack. This rack is driven by a vertical shaft and pinion, connected to the main driving shaft by a train of gearing. Thus the upper shell is

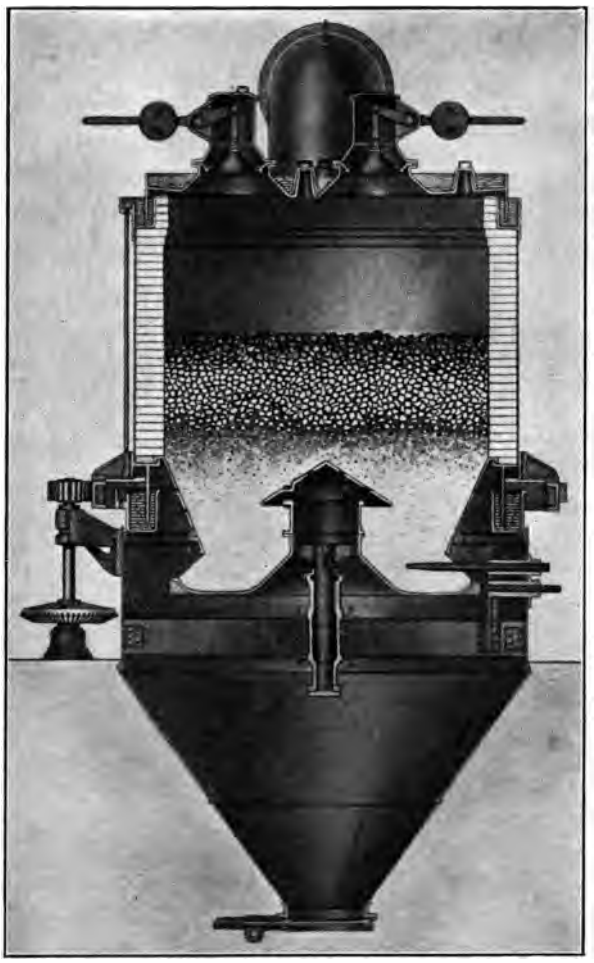


FIG. 24. HUGHES PRODUCER.

rotated as above mentioned. The tread of this steel rack travels on conical chilled-iron wheels having tight axles revolving in self-oiling boxes.

A further development as far as the rotation of the grate parts is concerned is the Kerpely producer, shown in Fig. 25. The rotating plate is developed as water seal and carries the grate, which

consists of several plates, through which the air passes into the producer. The lower part of the grate disintegrates the clinkers and the latter are automatically removed from the water seal by means of a shovel. One rotation is made in three hours.

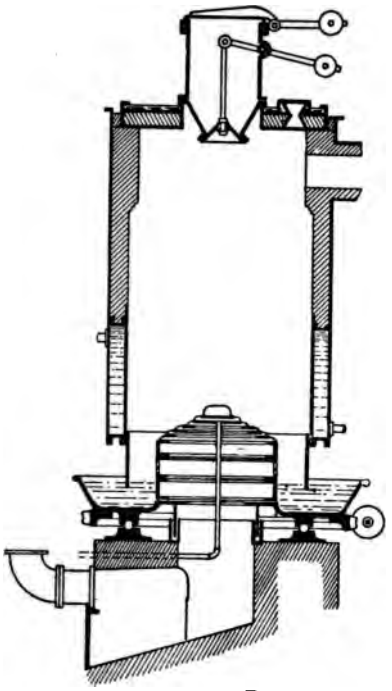


FIG. 25. KERPELY PRODUCER.

In the Rehmann producer the rotating part consists of suitably arranged cones, which are provided with perforations through which the air enters. The arrangement of the shovels for removing the ash is shown in Fig. 26. The larger pieces of clinkers are raked out, the smaller ones shoveled out.

In these producers the ash is loosened and the clinker disintegrated. We will now discuss the next step—the mechanically poked producers.

The Fraser-Talbot producer (Fig. 27) pokes the fuel by means of two agitators arranged on a vertical shaft.

The latest development along these lines is the Hughes producer (Fig. 28), in which the mechanical poker is a water-cooled steel casting suspended from a trunion. The poker is operated by ratchet gearing actuated by a crank and crank-shaft which is driven by a reduction gearing connected to the main shaft. This mechanism moves the poker back and forth, agitating and breaking up the mass of fuel and evenly distributes the coal and helps in working down the ashes for removal. The

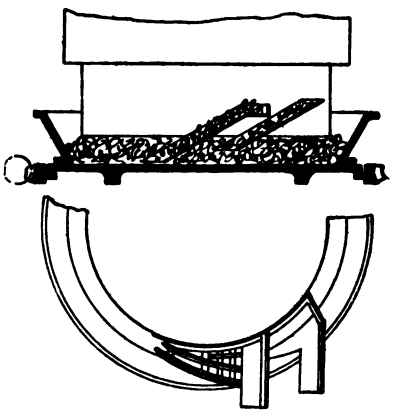


FIG. 26. ASH REMOVAL.

uniform treatment secured by the mechanical poker gives better and more uniform results as to quality, quantity and supply of gas, and reduces the cost of installation and operation. The power required to operate a single producer is 3 electric hp. Twenty-five pounds of coal are gasified per square foot.

Another way for the removal of clinkers is Blesinger's device, shown in Fig. 29. In this type so-called grate cars are used for receiving ash and clinkers.

For preventing the formation of clinkers on the walls of the producer, water cooling is applied more or less successfully. In

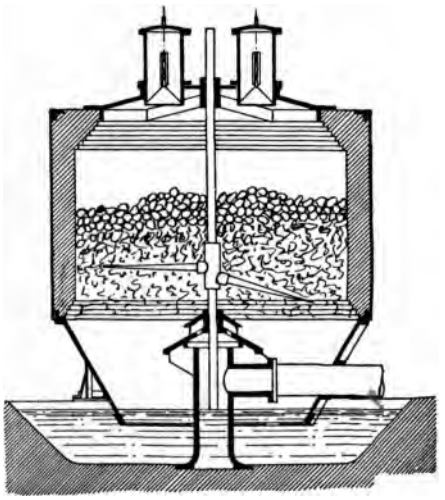


FIG. 27. FRASER-TALBOT PRODUCER.

order to prevent the formation of smoke during poking, the device shown in Fig. 30 is successfully used. When the lid of a poke hole is opened, a steam cock is simultaneously opened in the turning point, steam flows over the poke hole from these points, which prevents the escape of gas.

When bituminous coal is to be gasified, for applications where a clean gas is desirable, it is necessary to provide either some additional apparatus for the removal of the tar, or some device to prevent its formation. If we consider that every ton of coal converted into producer gas generates ten times as much gas as in the manufacture of coke, we can see that an apparatus for the complete removal of the tar must necessarily be of very considerable size. It is therefore desirable to prevent the formation of tar, thus

reducing the complication of the apparatus, and also utilizing the calorific value of the tar, instead of allowing it to go to waste.

In order to prevent the formation of tar the gas producer must be

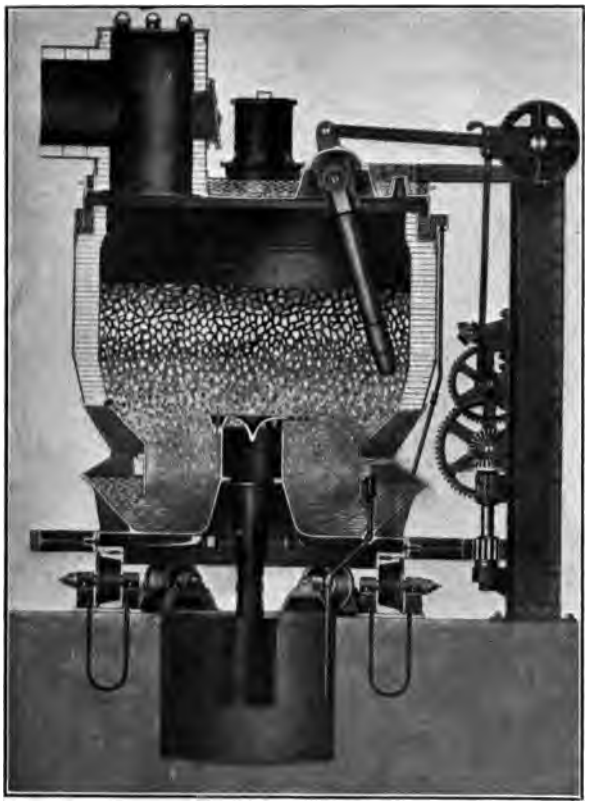


FIG. 28. HUGHES PRODUCER.

so arranged that the volatile constituents are decomposed, as far as possible, into hydrogen and carbon monoxide, for which reaction a high temperature is necessary. In approaching the incandescent part of the fuel bed the tar is liberated. It is for this reason that soft coal, used in an ordinary producer, generates a gas high in tarry contents. If the tarry gases are passed again through incandescent coal, the tar is converted into a fixed gas of high thermal value, consisting of hydrogen, carbon monoxide and some carbon dioxide.

Several methods have been proposed for the removal of the tar

in the producer itself, by decomposition in the zone of combustion. One of the simplest methods to this end appears in the down-draft system, of which the Letombe producer is an example. In this arrangement the green fuel is at one side of the zones of combustion and reduction. The fuel is charged upon the inclined step

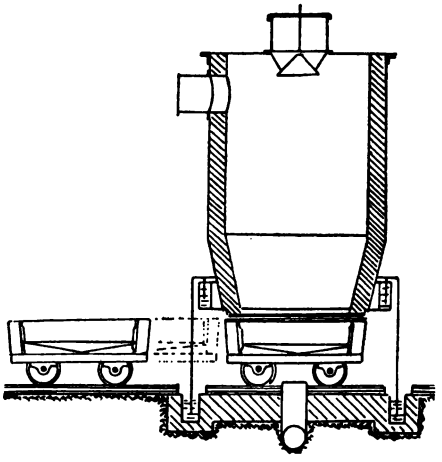


FIG. 29. REMOVAL OF CLINKERS.

grate *A* at the top, the air entering through the grate causing a partial combustion of the fuel and the distillation of the volatile matter. The bulk of the air, together with the moisture, enters at *B*, producing the zones of combustion and reduction at *C* and *D*. The gas is discharged at *E*. A small boiler *F* supplies the vapor necessary for the required amount of moisture. A number of

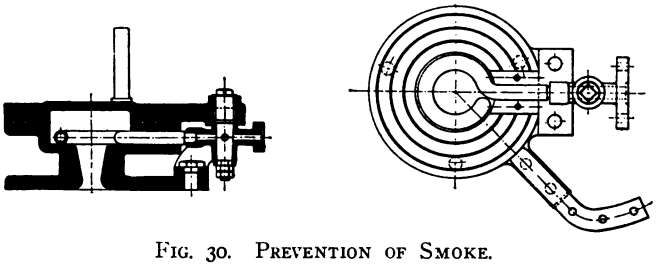


FIG. 30. PREVENTION OF SMOKE.

these producers have been installed, and in Mexico they are reported as having given good results with wood. The principal criticism to be made of this design is, that the accumulation of ash and slag behind the combustion zone is inconvenient.

Another method of getting rid of the tar is to collect the gases of distillation separately in the upper part of the producer, and

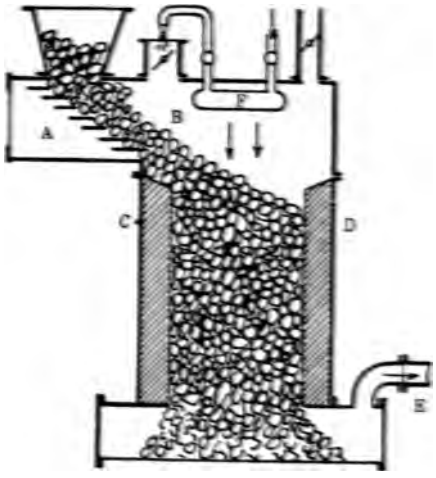


FIG. 31. THE LETOMBE PRODUCER.

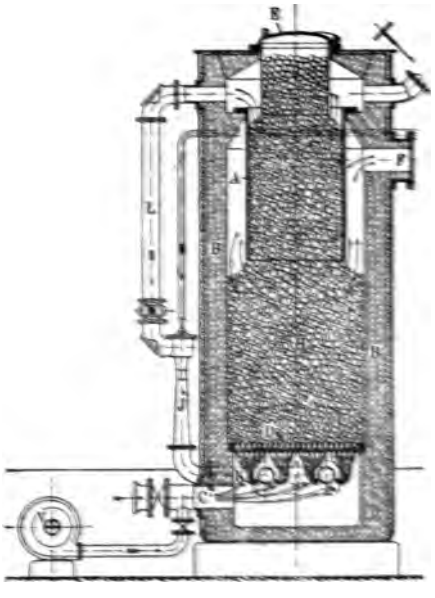


FIG. 32. THE PINTSCH PRODUCER.

then deliver them, by means of outside pipes and a steam jet, into the lower part of the producer, so that they pass through the fuel

bed a second time, together with the fresh-air supply. It has been found to be a very difficult problem to accomplish this successfully, and the quantity of tarry gases is not definitely known. Many producers upon this principle have been designed and operated with more or less success.

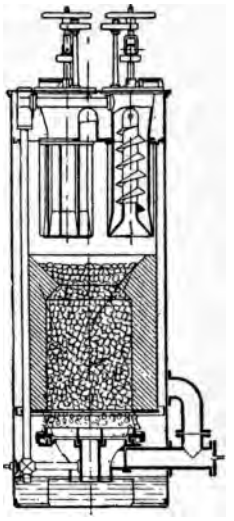


FIG. 33. THE CROSSLEY PRODUCER.

An example of this type of producer is that of Julius Pintsch, of Berlin. Here the green fuel contained in the fire-clay chamber *A* is heated by the gas as it passes out at *F*. The products of distillation are drawn off from the top through the pipe *L*, by means of the jet exhauster *j* and delivered into the bottom of the producer, where they mingle with the incoming air and pass up through the fuel bed *H*. A producer of the suction type, constructed according to this principle, is stated to be in successful operation in Denmark, using a mixture of coke and bituminous coal.

In the Crossley producer, shown in the illustration, the green coal is treated in retorts suspended in the upper part of the producer, these retorts being opened from time to time to permit the coked fuel to fall into the producer. The tarry gases are conducted to the bottom of the producer, as in the Pintsch type.

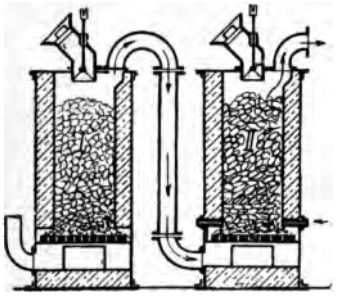


FIG. 34. DOUBLE PRODUCER.

A natural variant of the above principle appears in the use of two producers, one fed with bituminous coal, the tarry gases being passed through a second shaft charged with anthracite or coke. The Riche producer is designed on this principle, using wood in one shaft and coke in the other. A specially interesting construction for the use of two kinds of fuel appears in the inclined producer of Lencanchez. Here both fuels are used in one shaft, the inclined position causing them to remain separated. The coke is on top, so that the tarry gases produced from the bituminous coal are compelled to pass through it.

Some successful experiments in the production of a gas free from tar, using but one kind of fuel, have been made with a producer having two zones of combustion. An example of this type is seen in the Körting producer for gasifying lignite briquettes. The fuel

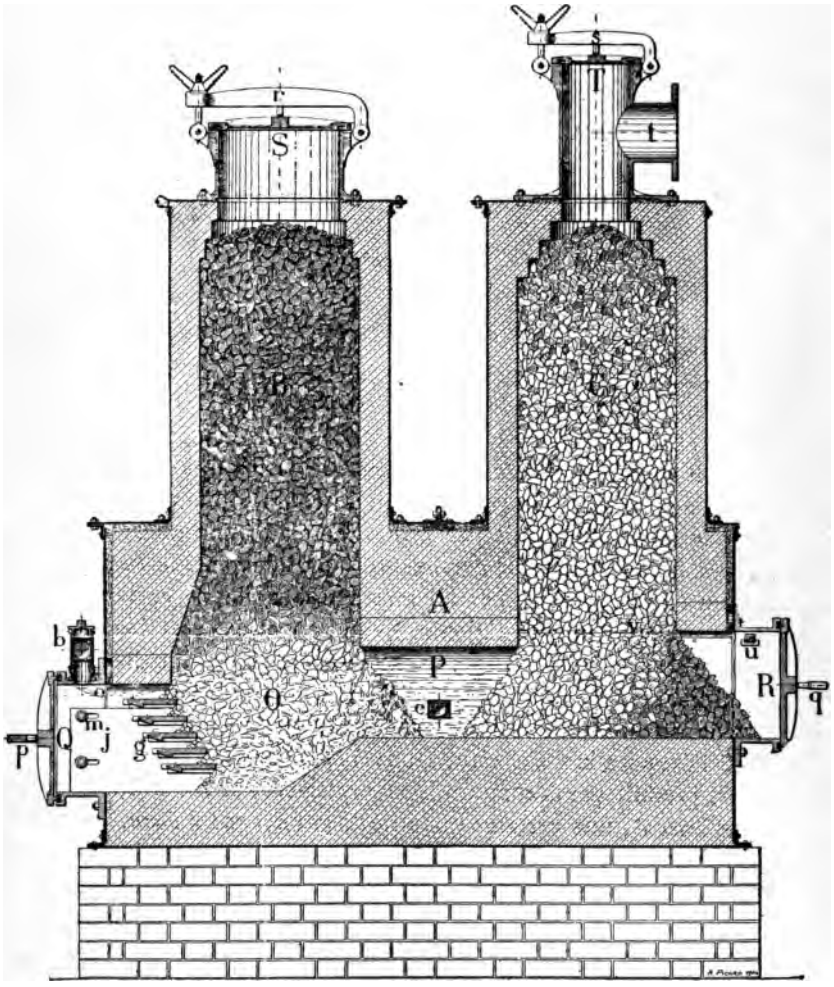


FIG. 35. RICHE DOUBLE PRODUCER FOR WOOD AND COKE.

is coked in the upper combustion zone *A*, where the distillation takes place, the quantity of air admitted being regulated by a slide. The tarry gases travel downward to the second combustion zone, the gas being taken off at *B*; the air supply for the second zone of

combustion enters through the grate. With this apparatus a gas has been obtained from peat or lignite containing as little tar or impurities, as gas from anthracite coal. This seems to point out the way for the successful gasification of bituminous coals.

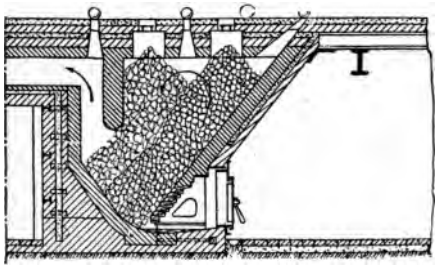


FIG. 36. LENCAUCHEZ INCLINED PRODUCER.

Finally, we may mention the Jahns producer, in which the lowest grades of bituminous coal, with a fixed-carbon content as low as 25 per cent., may be converted into gas free from tar.

Jahns generally combines four producers into one group, these being charged alternately with green fuel. The moist and tarry gases generated in the shafts containing the green coal are caused to pass through the adjoining shafts of the same group which are in full incandescence. In the Jahns system the shafts are alternately charged completely and entirely emptied. By allowing the large quantities of incandescent clinker to remain under the producer, the fresh charge can be quickly heated up. In actual practice, however, it has been found preferable to charge and discharge the shafts gradually. The arrangement of the Jahns producer system will be understood from the sectional elevation and plan.

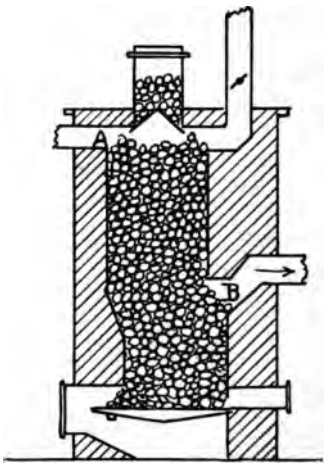


FIG. 37. KÖRTING PRODUCER FOR LIGNITE BRIQUETTES.

In the Mond system the coal is gasified for the purpose of recovering all the by-products, especially the ammonia, but the initial cost of this system renders it particularly available for very large units. Since all the by-products are utilized, the gas is very cheap.

The arrangement of producer plants and their connections naturally depends very much on local conditions. In fuel applications it is often desirable to locate the producer as near as practicable to the point at which the gas is to be burned, thus utilizing the sensible heat of the gas to a greater degree in burning at the higher

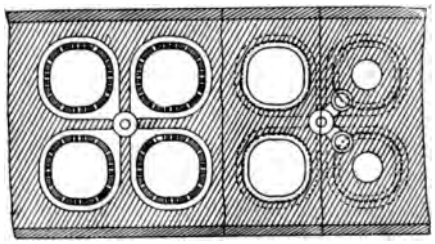


FIG. 38. SECTIONAL PLAN OF JAHNS PRODUCER.

temperature, while the outlay for connections is minimized. To this end, the connection should be properly lined, as far as may be, with fire-brick or other non-conducting material. They should be

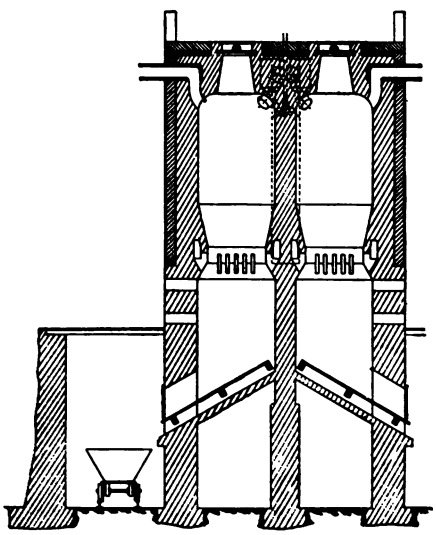


FIG. 39. SECTION OF JAHNS PRODUCER WITH FOUR SHAFTS.

laid out with a view to possible extensions, and provided with cleaning and safety or explosion doors.

Piping the Gas.—The flue or connections should be fire-brick lined for carrying hot gas and to reduce the radiation where the

sensible heat may be utilized. Deposits in the mains are favored by change in direction and velocity. Sufficient hand and manholes, as also suitable valves, relief doors or safety devices, should be

FIG. 40. RELIEF DOOR.

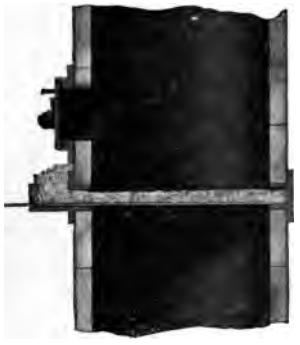


FIG. 42. PLATE SAND VALVE.

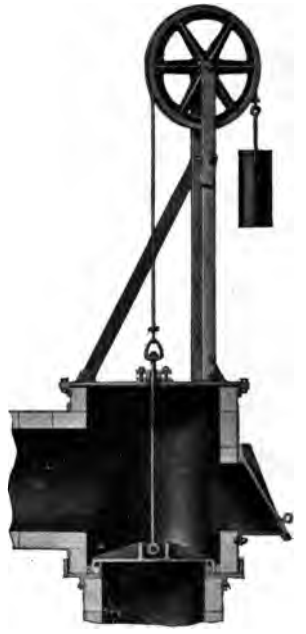


FIG. 41. ANGLE SAND VALVE.

provided. The heat loss in piping long distances is greater in bituminous than in anthracite gas. In the former the loss is increased, owing to the greater condensation and deposition of the

FIG. 43. CLEANING AND RELIEF DOORS.

FIG. 44. CLEANING DOOR.

unfixed heavy hydrocarbons, while with anthracite practically no loss results except from cooling. Probably 500 feet is the maximum distance to which bituminous producer gas should be carried,

and in such instances it is essential to have the flues of ample diameter—the greater the distance the larger the flue—making allowance, of course, for the partial consumption of the gas along the line. It is usually best to line the flues with fire-brick or other non-conducting material for their entire length, though cast-iron mains of small diameter, 18 inches or less, preferably protected with asbestos on the outside, are used for services which do not justify outlay for the larger lined mains.

FIG. 45. SOLID SEAT ANGLE VALVE.

Flue Areas.—Ample area of flue is important, and the more so in bituminous practice. In general, the diameter of the producer connection should be about one-quarter the diameter of the producer, and in a collecting flue from several producers its area in like proportion should be not less than one-sixteenth of the gas-making area of the attached producers. Thus a producer of eight feet inside diameter of lining should have a connection at least 24 inches internal diameter. As such a producer may readily gasify 600 pounds of coal hourly, the flue area is about equal to one square foot per 200 pounds of coal gasified hourly.

In soft coal practice it is necessary to *periodically burn out* the tar and soot deposited by the gas. This is done by stopping the producer and opening suitable doors provided in the flues. Usually the soot takes fire readily, or may be ignited, and the furnace stack draws the air and combustion through the flue. In some cases direct connection of the flue is made to the stack and air or steam jets used to loosen the deposits of soot, while at the accessible points it is scraped out.

Gas Reversing Valves.—In the industries in which producer gas is used as fuel in connection with regenerators, valves are used for reversing the current of gas. The old Siemens butterfly valve which is widely used, though considerable losses are occurring in same on account of leaks, is now being superseded by more modern constructions.

Figs. 46, 47 show a gas reversing valve of modern construction which is successfully used in a large number of European iron works. It has the advantage that it keeps tight for many years.

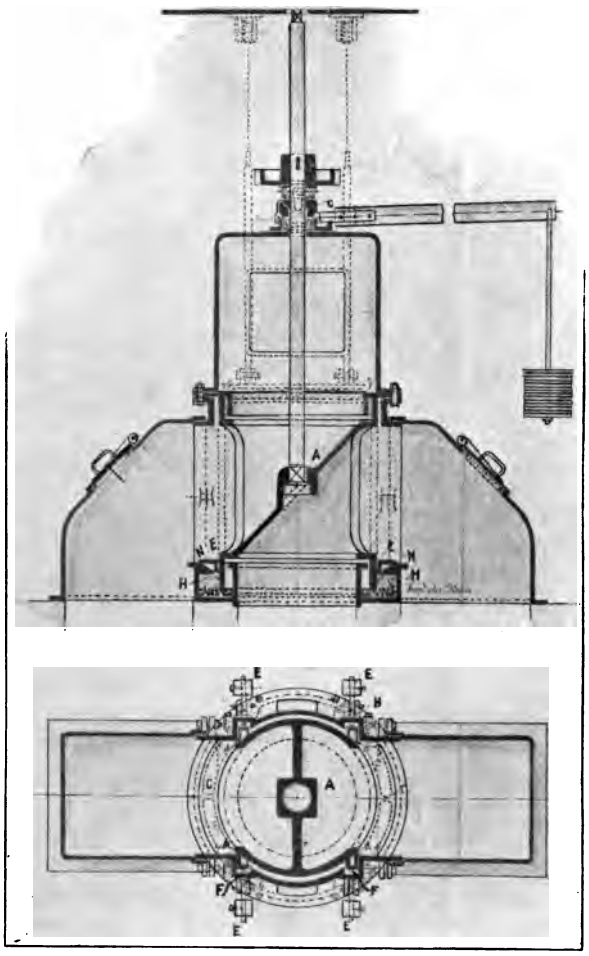


FIG. 46. GAS REVERSING VALVE.

does not warp and effects a saving in fuel which in many cases is very considerable.

This valve which is called the Fischer valve consists of three main parts, namely, an inner cylinder with a wall across; an outer cylinder which is made in four compartments with four ribs, and the base-plate.

The inner cylinder presses by the counter-weight to the lower face of the upper ring, whereby the upper joint is kept tight. The space of play between the inner cylinder and outer cylinder can be made as desired and the connection between the two cylinders is made

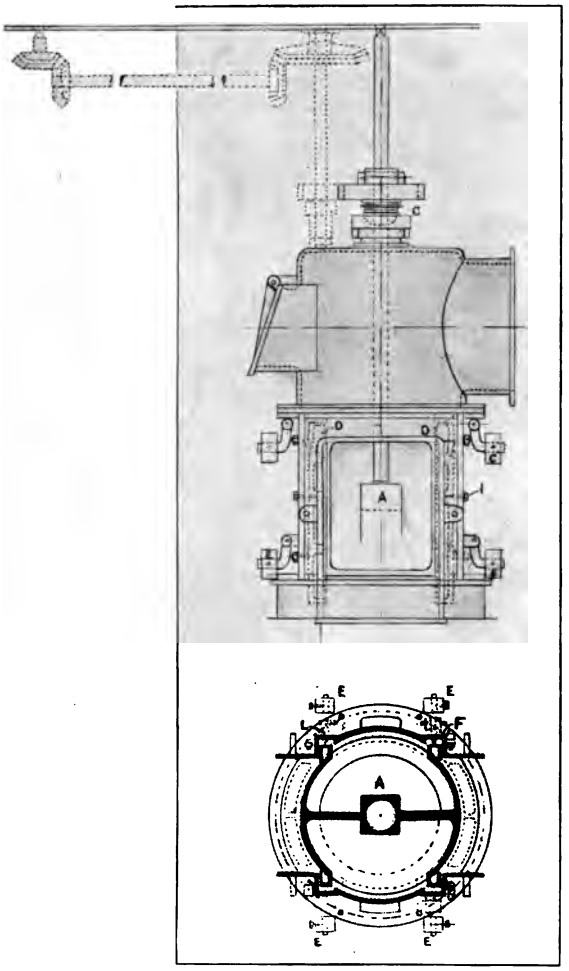


FIG. 47. GAS REVERSING VALVE.

by four ribs, which effect a tight joint on the sides. The four ribs are pressed by the weights against the inner cylinder. The ribs can be lifted by loosening the bolts *E*, whereby a connection is made from producer to stack for burning out the pipes, etc. The

lower joint is made tight by having the inner cylinder resting in sand on the base-plates. The inner cylinder rests in a ball-bearing which allows easy handling and rests on the button *p* whereby an absolutely horizontal position of the inner cylinder is effected. The gas current is reversed by turning the valve 180 degrees.

CHAPTER III.

THE COMBUSTION OF PRODUCER GAS.

High efficiency of combustion depends on thoroughness of the gas-air mixture and on preheating the air. In order to obtain a temperature of bright red incandescence it is imperative to preheat the air for combustion by exposing it to the temperature of the hot products of combustion passing to the stack.

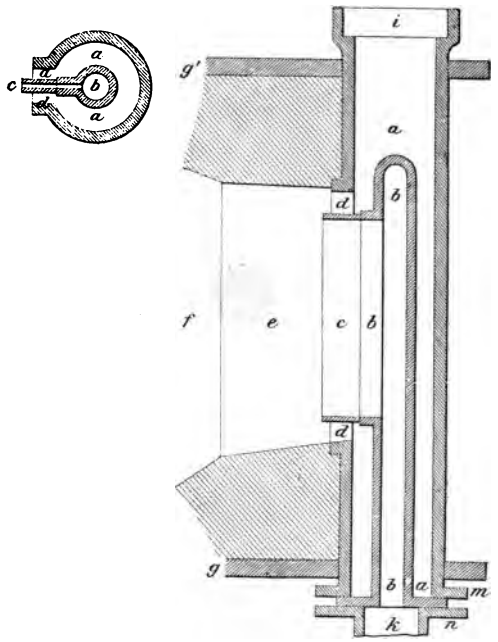


FIG. 48. MIXING DEVICE FOR GAS AND AIR.

A good many devices for mixing the gas and air consist simply of two concentric pipes, one for air and one for gas. In Fig. 48 we have a gas pipe *a*, an air pipe *b*, a collar *c*; *d* is the opening of the gas pipe, *e* the flue, *f* the hearth, *g* the front plate of the furnace, g^1 the back plate, *i* the connection to the gas line, *k* the connection to the air line. *b* can be turned around its axis between the flanges *m* and *n* in order to give the flame the desired angle toward the hearth.

For a downward direction of the flame, the burner shown in Fig. 49 is very practicable; *b* is the air, *a* is the gas pipe.

The manner in which gas and air meet is of great importance for proper combustion. By a suitable arrangement of the gas and air channels a long or short flame can be produced. If air and gas are brought together at right angles (Fig. 50) a rapid, concentrated combustion is effected. For every gas channel there is a corresponding air channel.

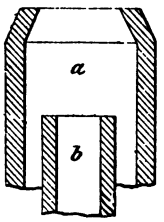
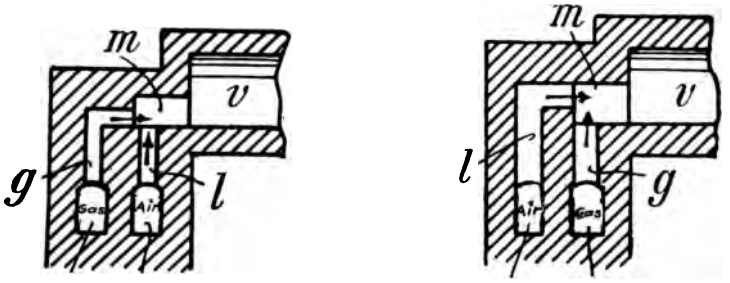


FIG. 49. MIXING OF GAS AND AIR.

The arrangement shown in Fig. 51 effects a more rapid combustion as the gas rises toward the horizontal air current. The air, on account of its higher specific gravity, rapidly mixes with the gas.

If the currents of gas and air are carried parallel into the furnace, the combination of gas and air is gradual and a long flame is the



FIGS. 50 AND 51. MIXING DEVICES FOR GAS AND AIR.

result (Fig. 52). The flame is shortened if gas and air enter at an angle (Fig. 53).

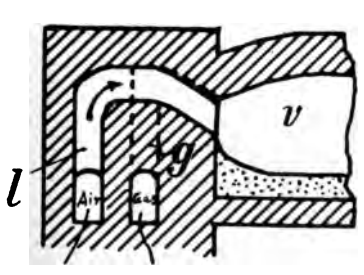


FIG. 52. MIXING DEVICE FOR GAS AND AIR.

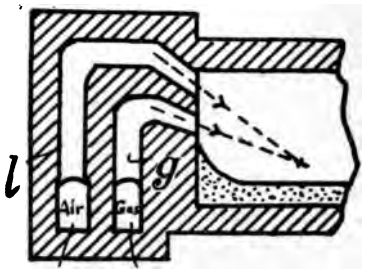


FIG. 53. MIXING DEVICE FOR GAS AND AIR.

Another method is shown in Fig. 54. The air enters through slit *l* and the gas is blown through, drawing along a sufficient amount of air from *l*. Gas and air meet in *m* and are burned in *v*.

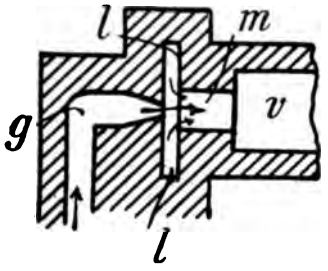


FIG. 54. MIXING DEVICE FOR GAS AND AIR.

The small furnaces used in the metal industries for tempering and annealing are still generally heated by illuminating gas or other rich gases. However, they can also be used for producer gas, if the gas and air have a sufficiently high pressure. The temperature obtained increases with the pressure.

In order to obtain the highest economy in gas-fired furnaces where high temperatures are to be reached, successful use may be made of the principle of regeneration, *i. e.*, of storing the waste heat in regenerators (heat storers consisting of chambers filled with fire-brick checker work). It is evident that the gas and air currents must travel in a direction opposite to that of the products of com-

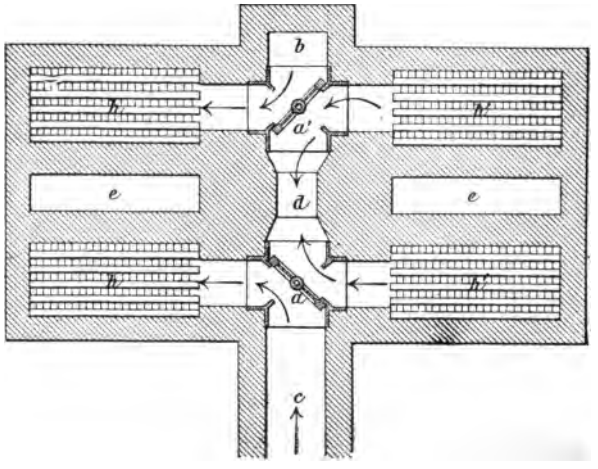


FIG. 55. REGENERATIVE SYSTEM.

bustion, if it is desired to transfer the sensible heat of the waste gases to the incoming gas and air. It follows that a regenerative furnace consists of two symmetrical parts, the axis of each going through the reversing mechanism. Each part consists of an air regenerator and a gas regenerator or of an air regenerator only.

The two air regenerators are connected by means of a reversing valve. Also the two gas regenerators.

Fig. 55 shows the plan of a regenerator system; *hh* are in the air, *h'h'* the gas regenerators, *a* the air, *a'* the gas-reversing valve, *c* the

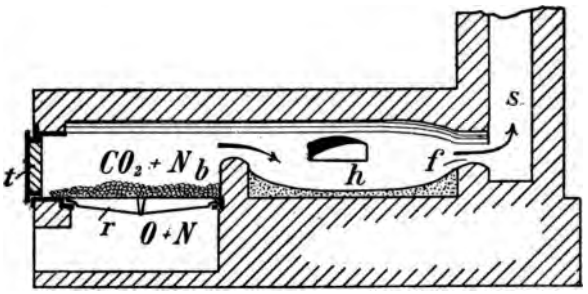


Fig. 56. Direct-fired Furnace.

gas main, *b* the opening for the air for combustion, *d* the stack. At the position of the valves shown air and gas travel to the left, combine in the flue above *e*, pass as flame over the hearth through the right-side regenerators and valves and leave through *d*.

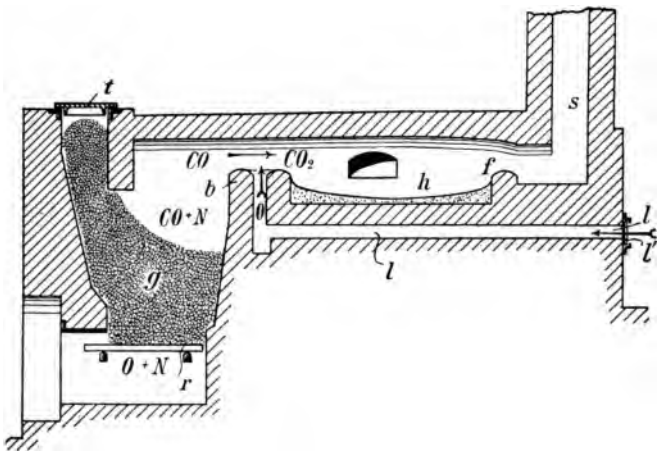


Fig. 57. Gas-fired Furnace.

For comparison of direct firing with gas firing we show in Fig. 56 a directly fired furnace and in Fig. 57 the same type of furnace after its transformation to gas firing. First of all, we note the more convenient way of charging the fuel to the gas-fired furnace, the fuel being charged through a door *t* on top, while with direct firing

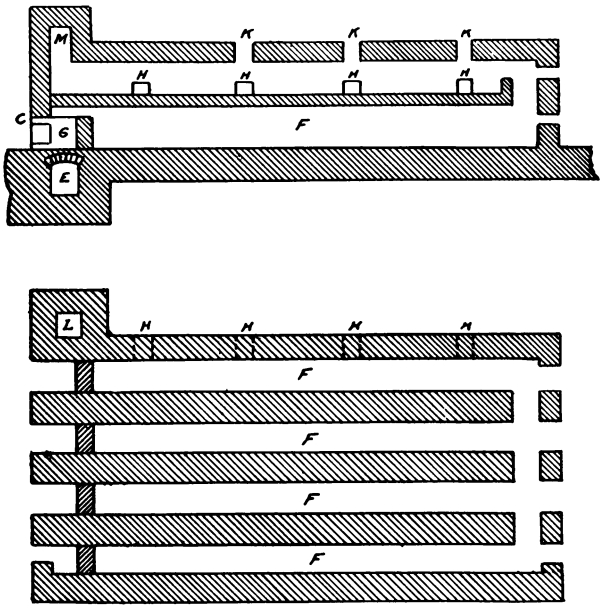
the fuel has to be thrown in through the front door. The grate *r* carries in the first case a low bed of fuel and complete combustion to carbon dioxide takes place. In the second construction (gas fire) the grate carries a high bed of fuel and the effective gas is carbon monoxide.

In the first type of furnace the products of complete combustion heat the hearth and escape through the stack, in the second type the complete combustion takes place at the hearth, just where it is wanted, and the heat stored in the fire-brick work below the hearth is utilized for preheating the air for combustion, passing through a flue *l* provided for this purpose. This comparison shows the greater convenience and higher economy of gas firing.

CHAPTER IV.

PRODUCER GAS-FIRED FURNACES IN THE CHEMICAL INDUSTRIES.

In the manufacture of sulphuric acid (chamber process) there is little difficulty in obtaining 95 per cent. acid in the platinum vessels, by the use of direct fire. If, however, 96 per cent. acid is to be obtained, the use of producer gas is preferable, and the latter must necessarily be used for the economical and continuous production of 97 to 98 per cent. acid, as with direct fire the proper heat cannot be kept up. The gas-fired furnaces used for this purpose are of the usual reverberatory type, the passage of the products of combustion being arranged on the counter-current principle.



FIGS. 58 AND 59. CHLORIDIZING ROASTING FURNACE.

For chloridizing roasting producer gas is commonly used in Europe. Figs. 58 to 59 show such a furnace. From the producer, which is not shown in the cut, the gas goes through sewer *E* to

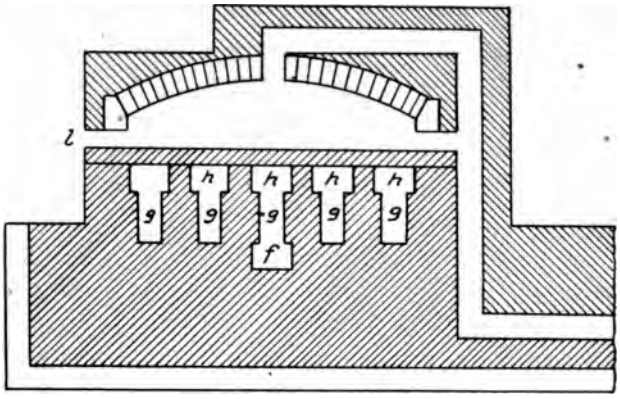
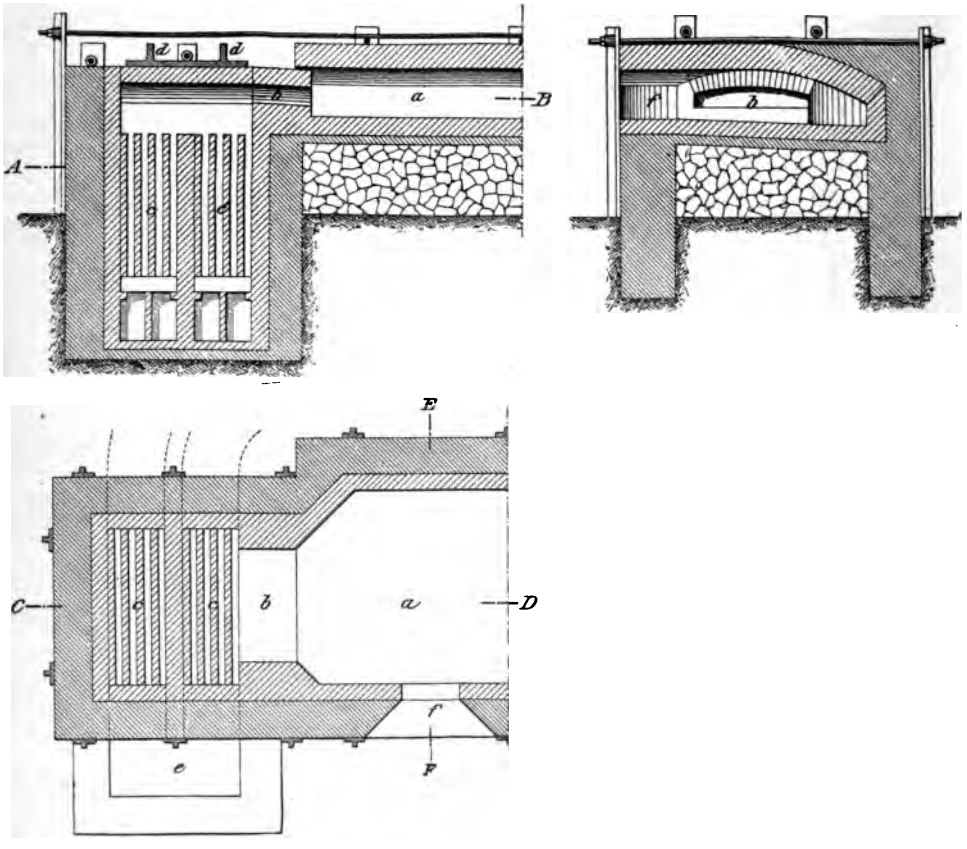
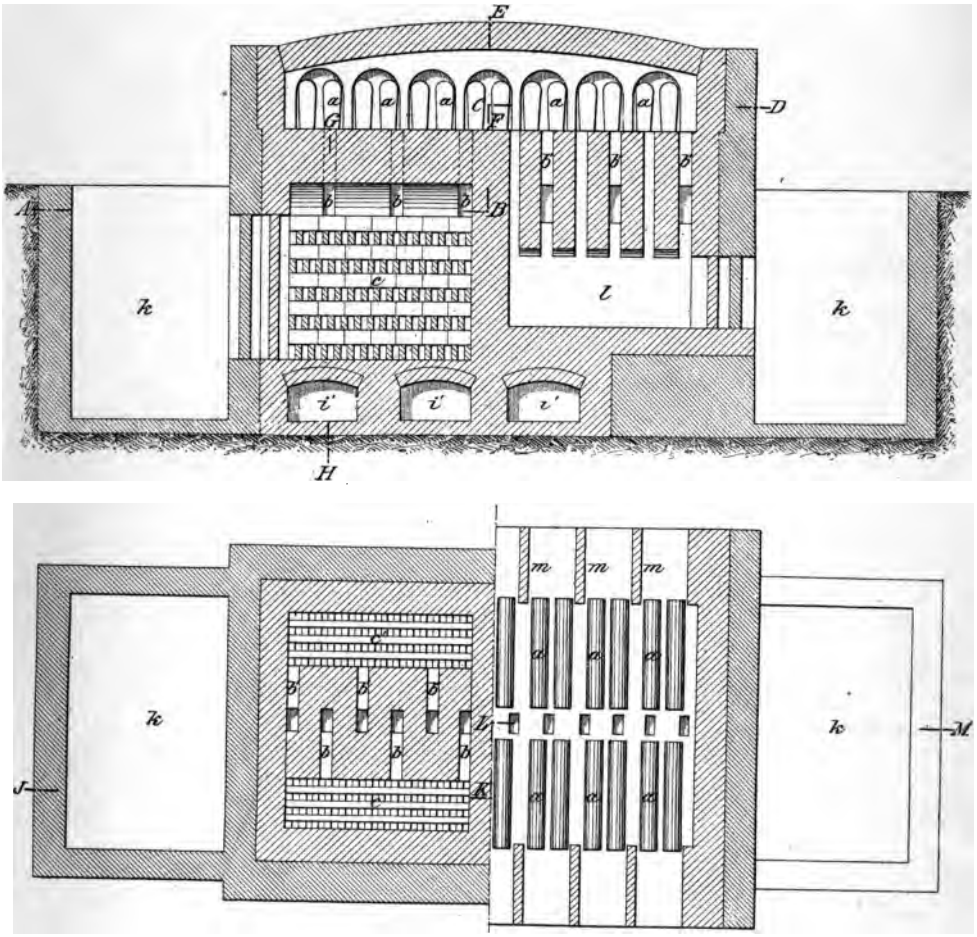


FIG. 60. CHLORIDIZING ROASTING FURNACE.



FIGS. 61, 62 AND 63. FURNACE FOR SMELTING SODA.

channels *G* and *F*, then over the charge through flue *M* to stack *L*. The combustion air enters at *c* and, if necessary, also at the other end of the furnace. The material is charged through *K* and worked through doors *H*.



FIGS. 64 AND 65. SECTIONS OF ZINC FURNACE.

Another construction of a furnace for chloridizing roasting is shown in Fig. 60. The gas goes through *f* and *g*, the air enters through *h*; *l* is a working door.

A German furnace for melting soda is shown in Figs. 61, 62 and 63. Fig. 61 shows one-half of a furnace on section *CD*, Fig. 62 section *EF* and Fig. 63 one-half on section *AB*; *a* is the hearth with

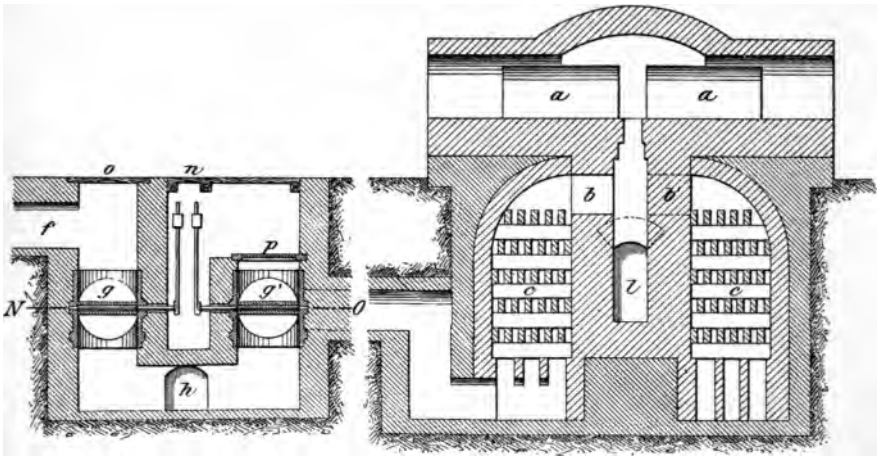


FIG. 66. SECTION OF ZINC FURNACE.

the working doors *f*, *b* the flue, *c* the air regenerator, *c'* the gas regenerator. On account of the flue dust, vertical walls are used in these regenerators instead of the ordinary checker work. In order

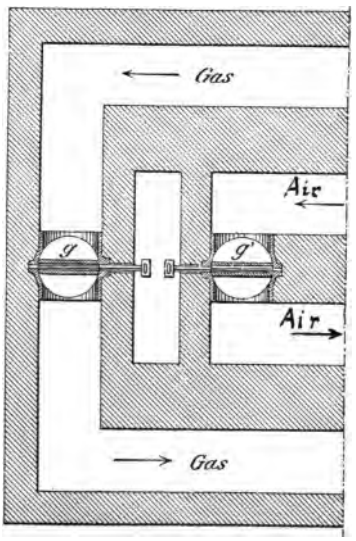


FIG. 67. SECTION THROUGH REVERSING VALVES.

to remove the flue dust, the cover *dd* is lifted up and the dust pushed down into pits *e*, after removing a few bricks.

The use of producer gas in zinc smelting is one of its most important applications. A typical construction, as used near Freiberg,

is shown in Fig. 64 (section *IKLM*), Fig. 65 (section *ABCD*), Fig. 66 (section *EFGH*) and Fig. 67 (section through reversing valves

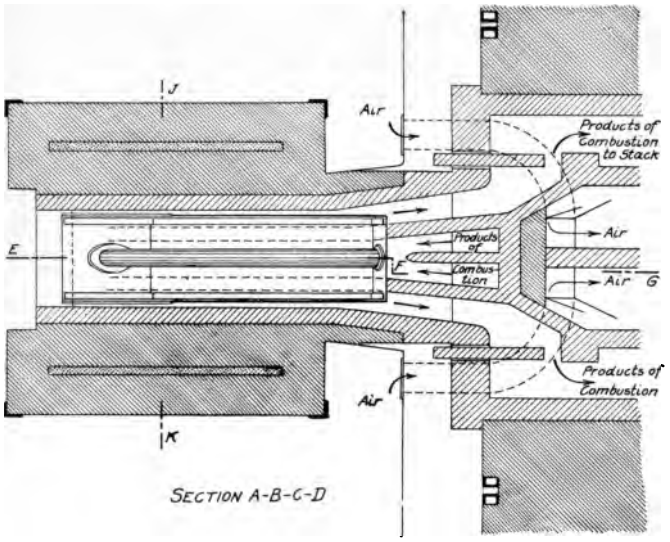


FIG. 68. SCHILLING-BUNTE FURNACE.

at *MN*); *aa* are the muffles, *bbb* the air slits, *b'b'b'* the gas slits, *cc* the air regenerators, *c'c'* the gas regenerators, *ii* the gas channels,

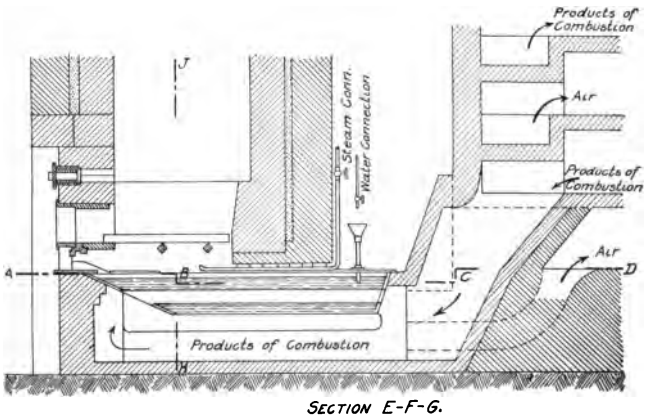


FIG. 69. SCHILLING-BUNTE FURNACE.

i'i' the air channels, *g* the gas valve, *g'* the air valve, *kk* the pits for getting at the regenerators in case of necessary repairs, *h* is the main flue, *mm* the walls separating the prolongs, *o* the cleaning cover

for the gas valve, p the air slide and n a cover, which is removed for changing the position of the valve levers.

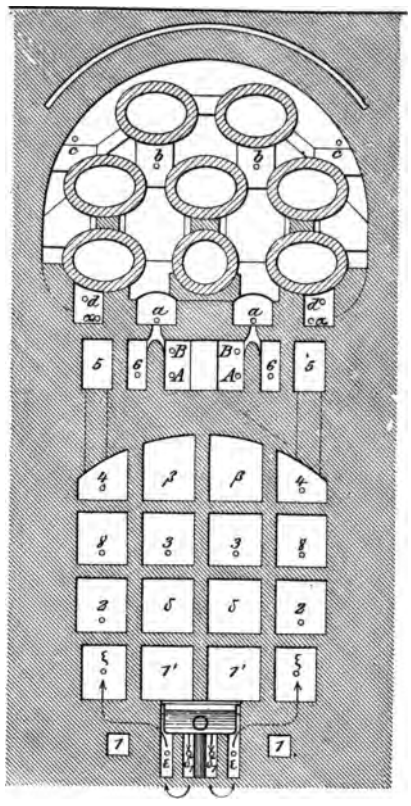


FIG. 70. SCHILLING-BUNTE FURNACE.

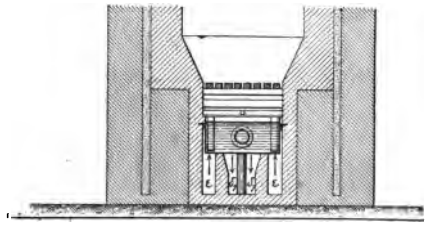


FIG. 71. SCHILLING-BUNTE FURNACE.

In heating gas retorts with producer gas a saving of over 25 per cent is effected. The Schilling-Bunte furnace is shown in Figs. 68 to 71, where 1 to 6 are the air channels, α to ζ the channels for

burning gas. The cold air enters at 1 into channel 1′, goes backward, passes into channel 2 and comes again to the front, goes over to channel 3, passes backward, travels through 4 forward, upward to 5, goes backward through 5 into 6 to the slits, where it meets the gas. The burned gases go at α downward to β, travel here forward, in opposite direction to the air, go backward in γ, forward in δ (from here they go through channels δ and ϵ, which are arranged below the vaporizer), and in ζ backward to the stack.

Gas-fired furnaces for the regeneration of bone-black have been in successful use since 1873. This process of regeneration requires

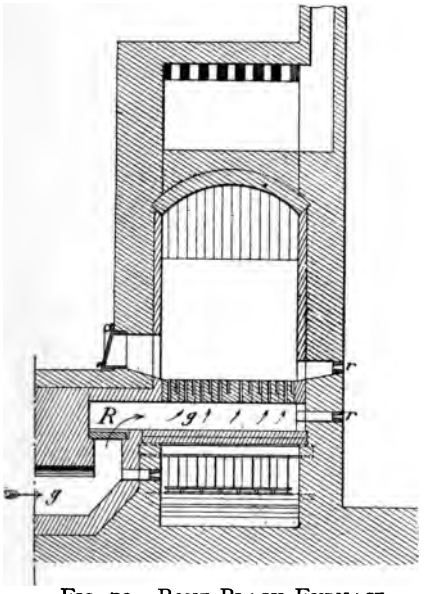


FIG. 72. BONE-BLACK FURNACE.

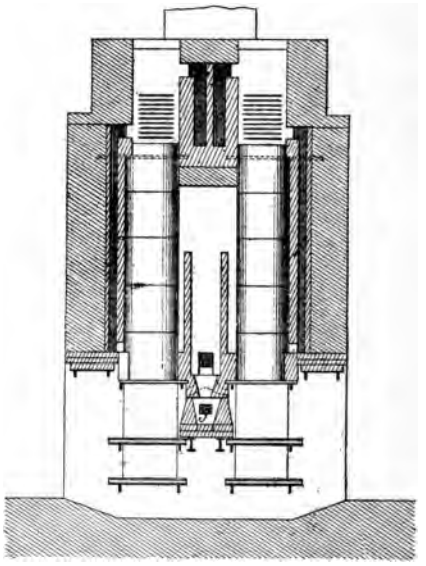


FIG. 73. BONE-BLACK FURNACE.

great exactness and causes considerable expense, as the production of a uniform product, which can only be obtained by uniform temperature, is very important. By using producer gas, the cost of labor is greatly reduced, since, with a fair grade of fuel, the producer works practically automatically.

With gas-firing the result of the process does not depend upon the intelligence of the workingman in charge; the temperature is easily regulated, and a great saving in fuel is effected. From time to time fresh bone-black is charged and at the same time a corresponding quantity of the regenerated product discharged.

There are in use furnaces with vertical or inclined cast-iron or fire-clay cylinders (retorts) of circular or oval cross-section of a diameter of 5 to 20 inches. The capacity of a furnace per 24 hours varies from 2½ tons to 15 tons.

There is no difficulty in applying gas-firing to furnaces of this kind. Figs. 72 and 73 show the firing of a furnace with 14 cylinders, with a capacity of 6 tons of regenerated bone-black per 24 hours.

The cylinders are arranged in two rows (seven in a row). In a similar way 12 to 15 cylinders can be set in one row. Between the two rows there is an open space of about 30 inches, which up to two thirds of the height of the cylinders is reduced by two thin fire-brick walls to about 18 inches.

The gas from the producer goes through channel *g*, is regulated at *R* and passes into the furnace proper through an arch provided with a number of outlet slits. The air also enters through slits provided in this arch, as shown in Fig. 73 by dotted lines. The air is preheated by the sensible heat of the incandescent, regenerated bone-black, and travels parallel to the gas.

The size and arrangement of the slits depend upon the capacity of the furnace. The flame rises between the two brick walls and then falls downward, playing around the cylinders. The products of combustion leave through channels *f* to flue *F*. On their way they come in contact with the material, since the cylinders are perforated, thereby drying and preheating same and increasing the economy of operation.

A direct-fired furnace can be easily changed for operation with producer gas.

For observing the temperature peep-holes *r* are provided as shown in Fig. 72.

Two or more furnaces can be supplied with gas from one producer.

Producer Gas-fired Reverberatory Furnace.—Reverberatory furnaces are widely used in the industries for melting, glowing, roasting and various chemical and metallurgical operations. Most of these furnaces, however, are at present still heated by direct firing, causing a great waste by fuel.

By providing such a furnace with producer gas firing, as shown in Fig. 74, a saving of 30 per cent. of fuel is effected. The change from direct fire to gas fire consists mainly in the addition of the

gas producer and recuperator between furnace and chimney. The recuperator consists mainly of a system of fire clay pipes e_1, which connect the flue b with the chimney E. This pipe system is built into a wider channel L, in which the air required for the combustion of the producer gas is introduced at l. The air goes in channel L around the pipe system as shown in the cut by arrows, absorbs the heat of the escaping fire gases and carries this heat back through the furnace to the channels and openings i. These channels are con-

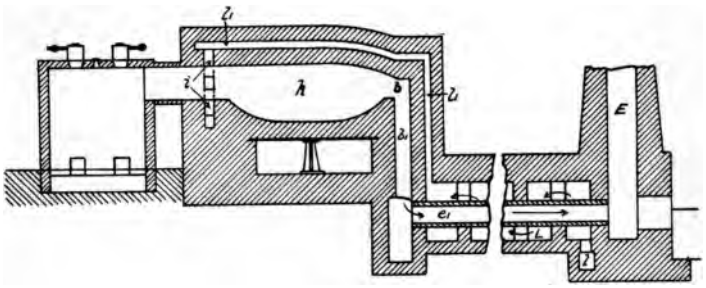


FIG. 74. PRODUCER GAS-FIRED REVERBERATORY FURNACE.

nected with the hot-air chamber L of the recuperator by air slits or air channels l'. In these air slits, which are arranged throughout the width of the furnace arch, the air is brought to a still higher temperature. Thence at the fire bridge incandescent producer gas is mixed with incandescent air, causing a perfect combustion. In working with a reducing flame the combustion is nearly smokeless. It gets perfectly smokeless by the use of a slight excess of air.

The saving is effected by higher temperature obtained, by the recovery of the heat in the recuperator, by reducing the radiation of the fireplace, by the exact regulability of the firing, and the perfect combustion. The life of the fire-brick work is considerably prolonged.

In installations where a temperature of 2000° F. to 3000° F. is required the gas and air have to be highly preheated before they are allowed to combine. This is effected by means of regenerators.

Producer Gas-fired Muffle Furnaces. In coal-fired muffle furnaces the combustion products escape at very high temperature after heating the muffle, which means a considerable loss of heat. Producer gas firing is much more economical in such a furnace, as the waste heat can be used advantageously for preheating the combus-

tion air. Furthermore the sensible heat of the brick walls can also be utilized for preheating air by providing suitable air slits. Fig. 75 shows a producer gas-fired muffle furnace in vertical section, horizontal section through the muffle proper, and a horizontal section through the recuperating apparatus.

The furnace shown in the cut is provided with two producers. The gas goes through openings *O* into the fire space *f* surrounding the muffle. At the entrance the gas is mixed with hot air, which is

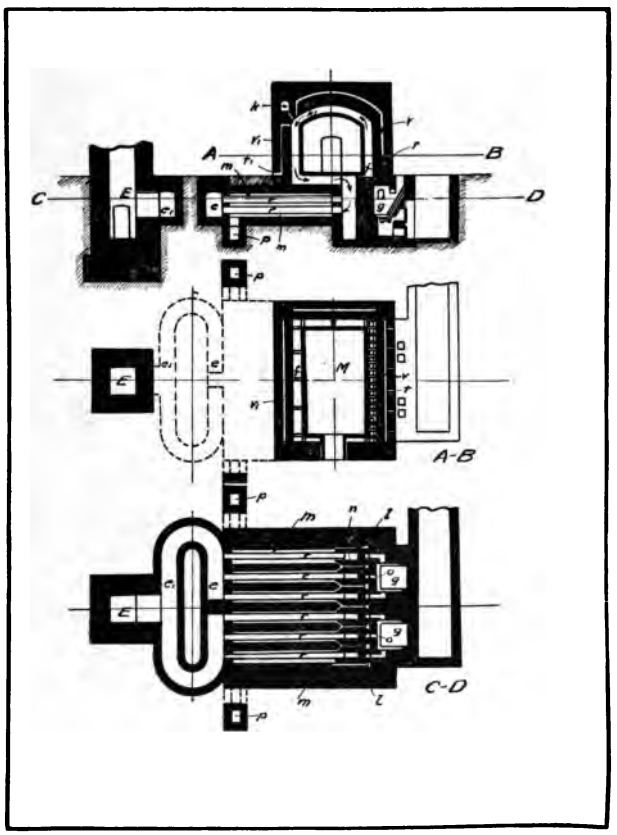


FIG. 75. PRODUCER GAS-FIRED MUFFLE FURNACE.

led to these points through channels *l* between the gas channels from the recuperator. The gas flame rises upwards, plays around the muffle arch and goes downwards, heating the bottom of the muffle. Then the products of combustion—still very hot—go through pipes *r* to the flues *ee* leading to the stack. The pipes *r* are built into

wider channels *m*, into which air is led through channels *p*. This air plays around the pipes *r* opposite to the flame direction, and is heated by absorbing through the pipe walls the heat of the combustion products. The highly preheated air finally goes through channels *n* into pipes *l*, which lead to the fire space and are arranged between the gas pipes.

For effecting a uniform heating of the muffle, the producer gas can be led into the fire space also at a second and third place, and the sensible heat of the brick walls utilized for preheating the air

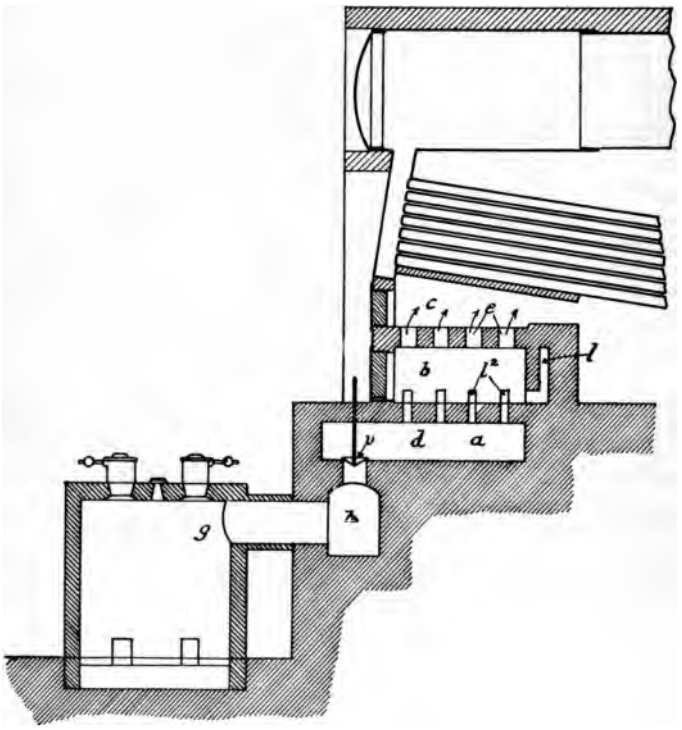


FIG. 76. PRODUCER GAS-FIRED BOILER PLANT.

necessary for oxidizing this quantity of gas. In the construction shown in Fig. 75, producer gas and preheated air is again allowed to enter at half the way of the fire gases around the muffle. The air necessary for burning this gas enters at *t* and t_1 through openings regulable by slides into the air slits *v*, v_1, arranged behind the fire-brick wall of the furnace. The producer gas entering at the second place is also taken from the producers.

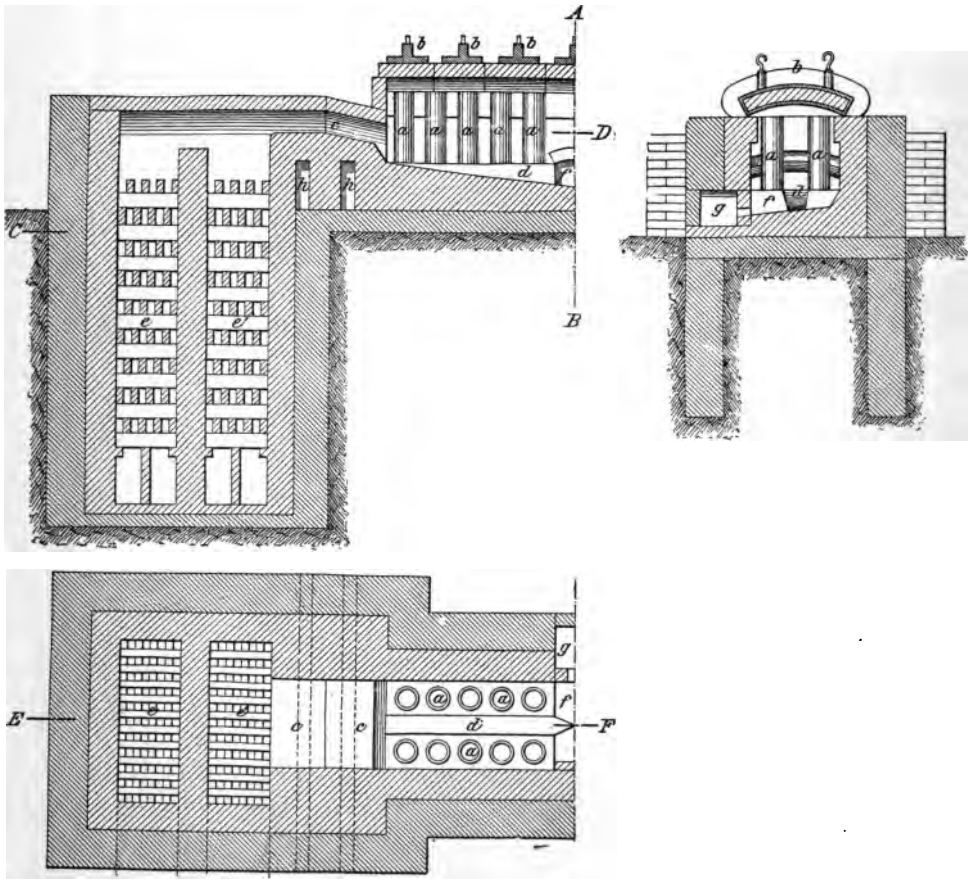
Producer Gas-fired Boiler Plant.—Fig. 76 shows a boiler installation provided with gas producer firing. It is easily understood that a battery of boilers can be heated by a battery of producers and that the boilers can be at any distance from the producers. In the plant shown in the illustration the producer gas goes at first to the gas sewer *h*, which is connected by valves *v* with the gas distributing channels *a*, one of the latter being arranged below every combustion chamber *b*. Thence by closing a valve any boiler can be disconnected from the firing and the quantity of gas to be admitted to the boiler be regulated. Above the channel combustion chambers *b* are provided, into which the gas enters by a number of openings or tuyeres *d* from the channels *a*. In the combustion chambers *b* the gas is mixed with the air required for combustion. The latter enters through channels, goes through channels *l* (in the side walls of the combustion chamber) downward to the opening l^2l^2, through which it enters at both sides of the tuyeres *d*, and is burned. Above the chambers *b* there are arranged chambers *c*, which are separated by an arch from the boiler tubes. Thence the fire gases before touching the tubes have to pass two chambers, first the combustion chamber proper and then the upper combustion chamber, whereby a complete combustion of the gas is obtained. The arrangement of the channels *l* prevents a loss of heat by radiation.

Coal is charged into the producer every half hour; as unskilled laborers can be used for this work, a considerable saving is effected, as compared to direct firing with skilled firemen.

CHAPTER V.

PRODUCER GAS-FIRED FURNACES IN THE METAL INDUSTRIES.

While in Europe producer gas is widely employed in the chemical and metallurgical industries, in most of the American factories

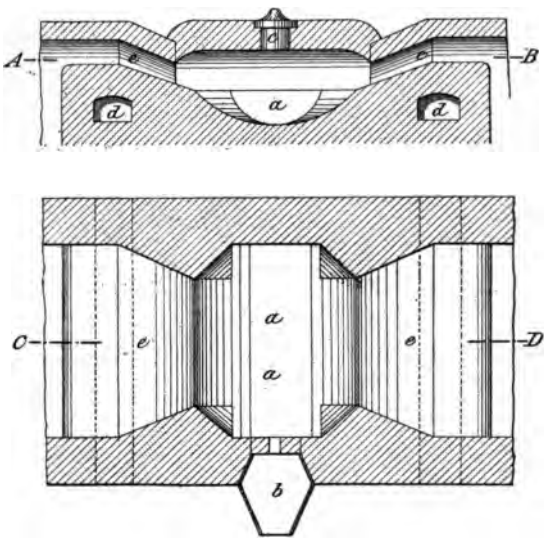


FIGS. 77, 78 AND 79. PRODUCER GAS FURNACE FOR SMALL CASTINGS.

direct firing is still in use, although the advantages offered by producer gas are indisputable. The slow progress in the change from direct firing to gas firing in this country is possibly due to the fact

that American manufacturers are not yet sufficiently familiar with the construction of producer-gas-fired furnaces suitable for their purposes. It may, therefore, be of interest to describe a few types of such furnaces which have been used successfully abroad for a good many years.

For small steel castings the furnace shown in Figs. 77 to 79 has proven an economical success. Fig. 77 is a vertical longitudinal section, Fig. 79 a vertical cross-section along line *AB* of Fig. 77,



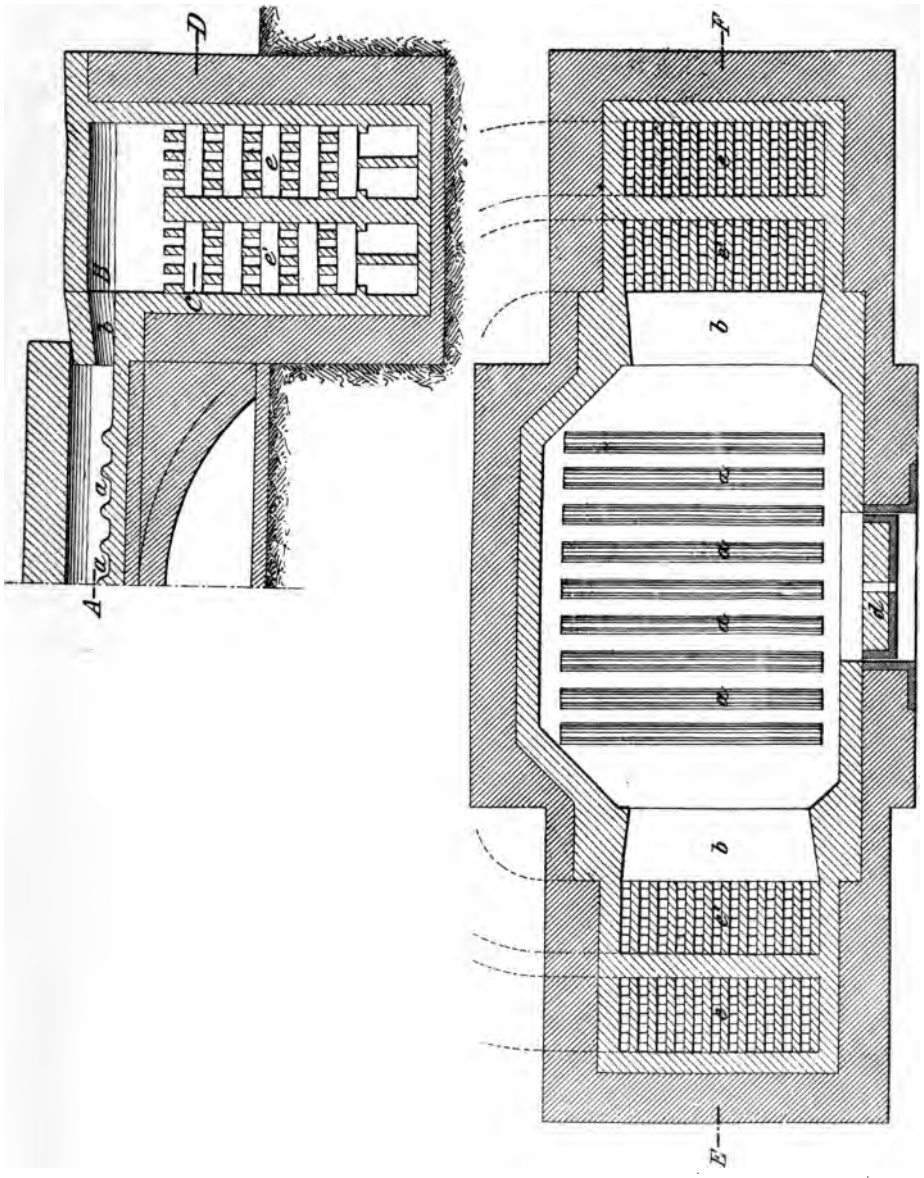
FIGS. 80 AND 81. REVERBERATORY FURNACE FOR SMALL-SIZE METAL CASTINGS.

and Fig. 78 a horizontal section along lines *CD* of Fig. 77. These furnaces contain 20 crucibles and are built under ground up to the sole of the hearth, so as to enable the operator to easily lift the arch covers *bb* and to get hold of the crucibles *aa* by means of suitable tongues. *c* is the air regenerator, *e'* the gas regenerator. The steel runs off through *d*, is collected at *f* and discharged at *g*. *c* is the flue, *hh* the cooling channels, which are connected with the stack.

The life of the crucibles is as long as with direct firing; with cast steel the operation takes about four hours and the hearth is to be renewed after every 52 operations.

A reverberatory furnace with regenerative gas firing for the manufacture of small-sized metal castings is shown in Fig. 80

(vertical section along *CD*) and Fig. 81 (horizontal section along *AB*). *a* is the "crucible," made of best fire clay; *b* is the charging



FIGS. 82 AND 83. REGENERATIVE GAS FURNACE FOR HEATING COPPER PLATES.

and discharging opening; *ee* are the flues; *dd* are the cooling channels, and *c* is an opening (which can be closed) for charging during the melting operation. The pieces of iron or metal can be some-

what preheated in the channels *dd*, which always get dark red at a welding heat. In shipyards these furnaces are very convenient for casting screws, etc.

A regenerative gas furnace for the heat treatment of copper is shown in sections in Figs. 82 and 83. The hearth is provided with corrugations *aa* for enabling the operator to conveniently get hold of the sheet metal. *b* is the flue, *e* the air regenerator, *e'* the gas

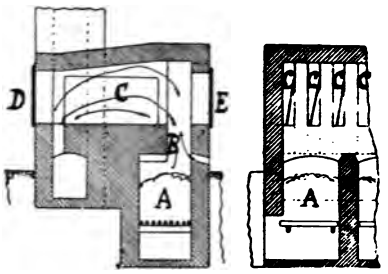


FIG. 84. FURNACE FOR METAL SHEETS.

regenerator, and *d* the working door, which is provided with a counterweight.

A copper plate of about 90 lb. gets red hot in 7 or 8 minutes and in 12 hours 3 to 3½ tons of sheet metal are rolled; the coal consumption is about 1½ tons.

This furnace is provided with a very low arch so as to keep the heat nearer the large area of the hearth. It is, of course, necessary to build these arches of sufficient strength.

By using producer gas in this furnace, the formation of oxide is much less than with direct firing. This means a higher economy, since the yield of metal is increased and the time of treatment is reduced as a result of the diminution of the quantity of oxide formed, which is a non-conductor of heat.

A furnace for heating sheet metal is shown in Fig. 84. It consists of the producer *A*, the combustion chamber *B*, where gas and air are mixed; the chambers *C*, which are separated by vertical walls and contain the charge, and the charging doors *D* and *E*. All chambers communicate at one end with the combustion space, and at the other end with the flue.

Fig. 85 shows a crucible furnace for 36 crucibles, constructed by Dawson, Robinson & Pope (Brightside Steel Works, in Sheffield). It is said to work very satisfactorily.

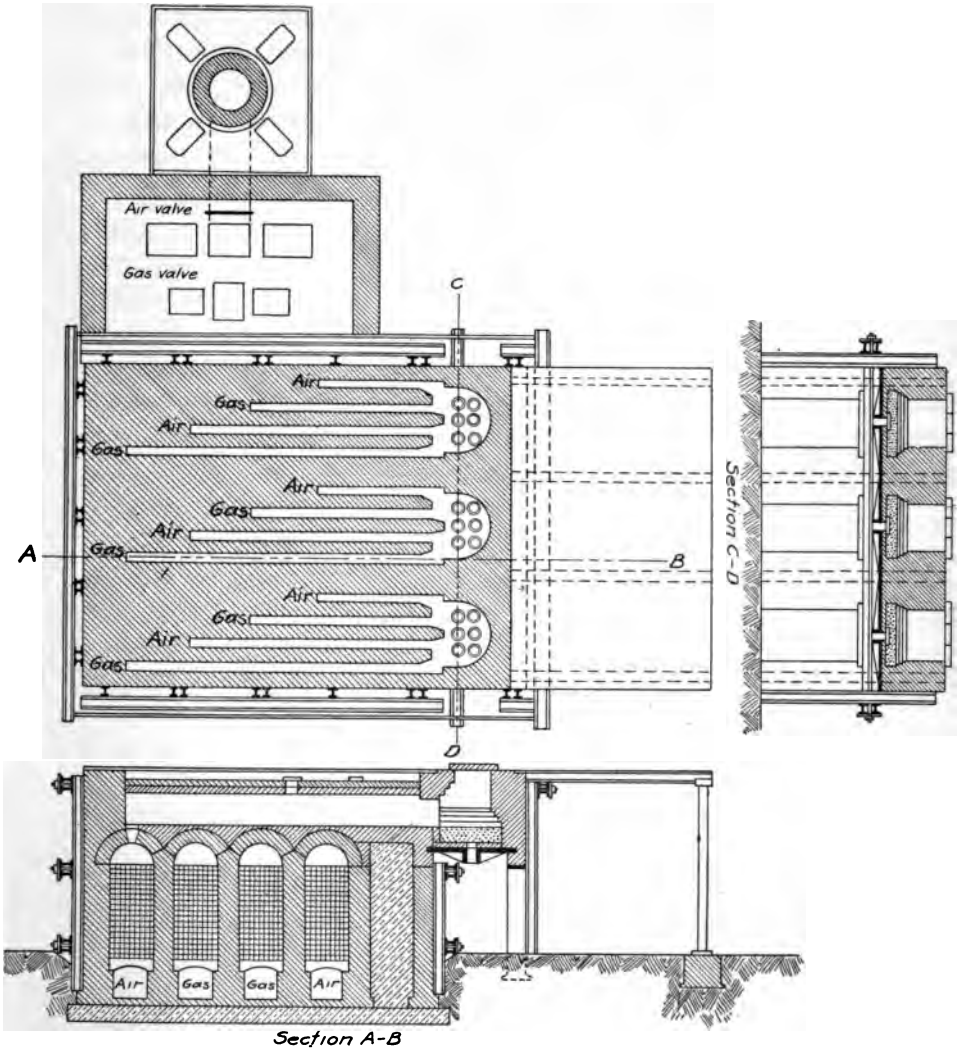


FIG. 85. CRUCIBLE FURNACE.

FURNACES FOR THE ENAMELING INDUSTRY.[1]

Where small quantities of high grade enamels are wanted, such as are used for watch dials, jewelry, etc., the crucible or pot furnace has its advantages, also for experimental work. It takes less time and fuel to smelt a heat in a properly constructed crucible furnace; on the other hand, only a comparatively small quantity of enamel is

[1] *Iron Age*, 1908.

obtained per heat. Crucible furnaces can be operated either singly or arranged in groups of nine pots or more. They are charged from above and the smelted enamel is poured off underneath by removing the clay prop covering the small hole in the bottom of the pot.

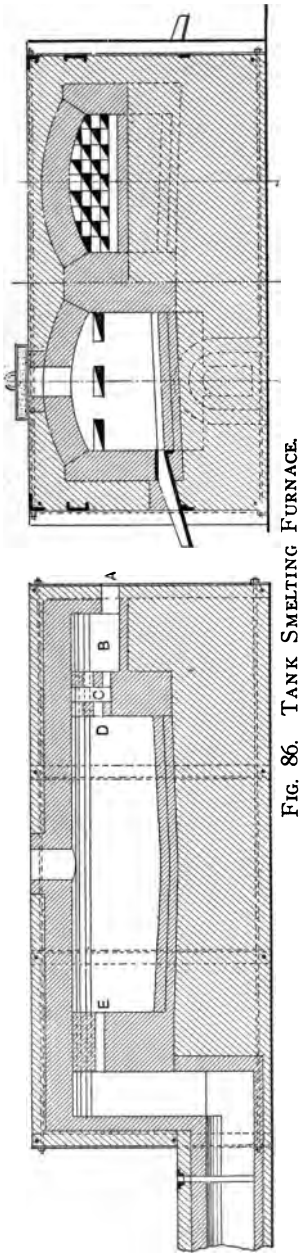


FIG. 86. TANK SMELTING FURNACE.

Formerly crucible furnaces were much used for the manufacture of colored enamels. At present enamel colors are mostly added to the mill and ground with the enamel or glaze; therefore this type of furnace is not so much seen any more in enameling plants.

Tank furnaces are needed wherever large quantities of enamels of the same kind are required. Their construction resembles that of the glass tanks. The receptacle for the enamel is a large square or rectangular basin formed of tiles and slabs of refractories, with a bottom sloped so that the liquid contents of the tank will drain to the lowest point where the enamel runs through a spout to the outside into suitable receptacles. To obtain uniform and satisfactory results it is necessary to have a well constructed furnace, well adapted to the kind of fuel that is supposed to be used.

Furnaces with direct coal fire should have fireboxes with a large grate area requiring only low draft pressure, so as not to tear ashes along. They should be so built that the flame will fully develop before passing over the smelting tank. To prevent contamination of the enamel by cinder and other impurities, the tank should be rather short with a sufficiently high roof, so as not to force the flame into the tank. The flame

should be clear and have a fairly straight current, strong enough to carry, without reverberating, any impurities over the tank into the stack. The openings leading to the stack can be rather large to prevent choking of the draft. Coal containing a high percentage of sulphur is unfit for use, as sulphur is very detrimental to enamels, causing blisters and other defects.

Smelters heated by producer gas have the advantage of a greater and more uniform heat, developing a clear flame that carries less impurities. As a consequence, it takes less time to make a smelt and a better grade of enamel is obtained. Natural gas is an ideal fuel for enameling purposes, but, of course, limited to certain localities.

To economize in space, cost of construction and fuel, tank furnaces are frequently built in pairs, with tanks side by side as illustrated in Fig. 86. This double smelter was designed for natural gas, but can be simply transformed for producer gas. Gas and air enter at point *A*, both unite and ignite in the combustion chamber *B*, pass through baffle bricks or checker work *C* at which point the fully developed flame enters tank *D*, spreading over it and smelting its contents. The flame leaves the tank through outlets *E* to the flue connections.

An arrangement of double smelters so constructed that the off gases of the first tank will smelt the contents of the second, may appear to be at first glance a great saving in fuel, yet it is not advisable, as the flame will always carry some of the contents of the first tank into the second, and thus contaminate the contents of the latter. Another disadvantage is that in cases of repairs both tanks have to remain idle.

Should a continuous demand for enamel warrant it, smelters can be built either with regenerative or recuperative devices, which while somewhat expensive will permit a better utilization of waste heat.

The enamel is burnt or fused to the metal in muffle furnaces, so called from the retort or muffle which serves as a receptacle for the ware to be enameled. The muffle is supposed to protect the ware from direct contact with the flames and impurities carried by them, such as ashes and cinders. It must be so constructed that it will absorb the furnace heat and radiate it toward the inside uniformly at an even temperature, sufficient to fuse the enamel on the steel

ware and to give the glossy porcelain-like appearance we are familiar with. This object is easily obtained by small muffles of retort shape made in one piece.

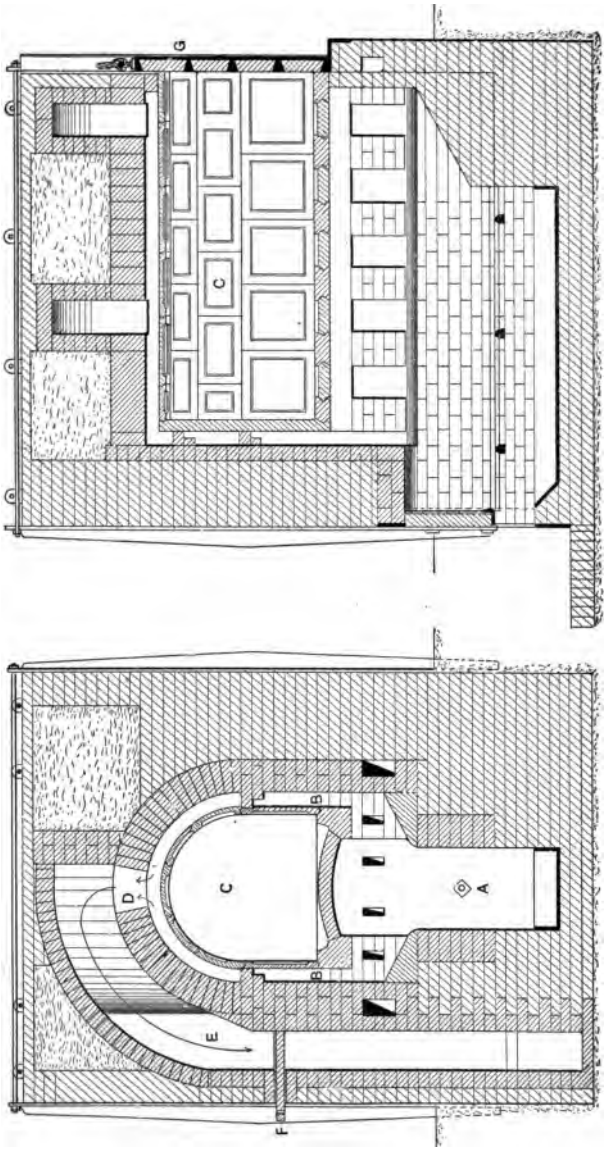


FIG. 87. SECTIONS THROUGH MUFFLE FURNACE.

With large furnaces, however, the proper design and construction of muffles is a very serious problem, since they have to be built in sections out of special tiles. Owing to the action of heat, these

muffle tiles will expand and contract, abrase at the joints and finally crack and chip, and thus permit an entrance of the flames.

The general arrangement of muffle furnaces is shown in Fig. 87. The fuel (in this particular case oil or natural gas) enters the combustion chamber at point *A*. The ignited gases travel through the opening *B* around both sides and back of the muffle *C*, uniting at the top. The two openings *D* connect with the flue *E*. The current of the flame is regulated by a damper *F*.

This muffle is closed by means of a door *G*, which is lined with firebrick and slides on guides. To overcome the weight of this door balance weights, either on levers or operated by means of sheaves with wire ropes, are used. For large muffles air hoists are preferable, provided compressed air is obtainable. The charging apparatus in such cases is also operated by means of compressed air.

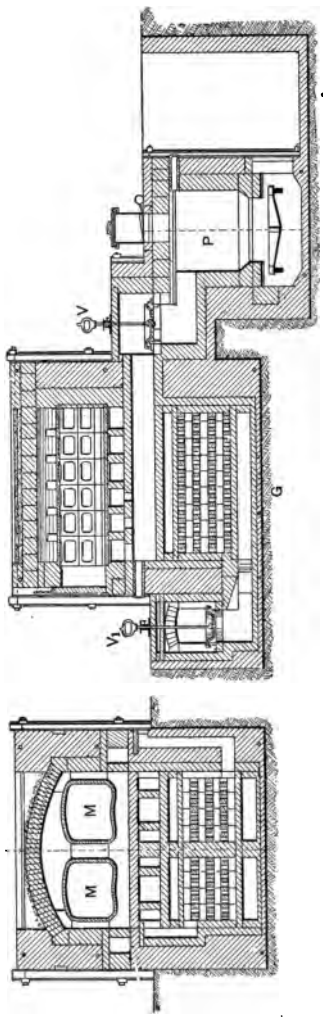


FIG. 88. TWIN MUFFLE FURNACE WITH GAS PRODUCER.

Fig. 88 shows twin muffle furnaces, as frequently built by Germany. The gas producer is arranged behind the muffle and does not present any unusual features. A valve *V* regulates the quantity of gas admitted into each side of the furnace; two other valves—*V* 1—located in front at the side of the furnace admit the air which passes through one regenerative chamber *G*, while the off gases pass through the other chamber; thus the two muffles are heated and used alternately.

As soon as one muffle has the proper temperature for burning the ware by means of the absorbed heat the valves are reversed and the second muffle gets the benefit of the flame, while the burnt ware from the first one is removed and the muffle charged again.

Muffle and smelting furnaces suffer through irregular production. Their construction suits them best for continuous operation. It results in a great waste of fuel to operate them intermittently or at long intervals. It takes nearly a day to bring either of these furnaces from the low temperature to a working heat, besides the sudden changes of temperature resulting from intermittent operation ruins the brick work, especially such parts as the muffle or tanks of the smelters, which will soon crack and become defective.

It is erroneous to suppose that the nature of the flame in a smelting or muffle furnace is immaterial, providing sufficient heat is obtained. Defective muffles will admit fire gases, which will frequently affect the ware to be burned, in various ways. Blisters or pin holes may occur, or the ware may lack in gloss or be discolored. Such phenomena are in many cases not caused by the enamel or impurities carried by the flame, but are the result of imperfect combustion owing to lack of oxygen.

If in such cases the combustion gases had contained a slight excess of oxygen, such defects might not have occurred. Reducing flames or flames lacking oxygen will absorb oxygen from the chemicals, especially the metallic oxides, of which the enamel consists. White enamel, for instance, exposed to reducing flames, provided same contains oxide of lead, will discolor and even turn dark gray or black. Enamels containing oxide of iron will have a greenish tint in place of being brown; such containing oxide of copper in place of green may turn reddish or brown in a reducing flame. Therefore, especially in muffle furnaces, the fire gases should be neutral or even contain a slight excess of oxygen.

CHAPTER VI.

PRODUCER GAS-FIRED FURNACES IN THE IRON AND STEEL INDUSTRIES.

The author has collected here illustrations of a great many types of furnaces in common use in the iron and steel industries, which are fired with producer gas. It is thought that a collection of authentic drawings of furnaces which are actually installed in iron and steel works will prove of value for purposes of reference and for showing just what has been accomplished in this line of work.

In Figs. 89 and 90 is shown a simple puddling furnace designed by Anton Mueller in Klagenfurt, Austria. The producer is con-

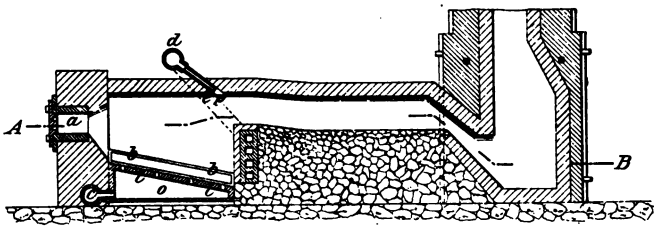


FIG. 89.

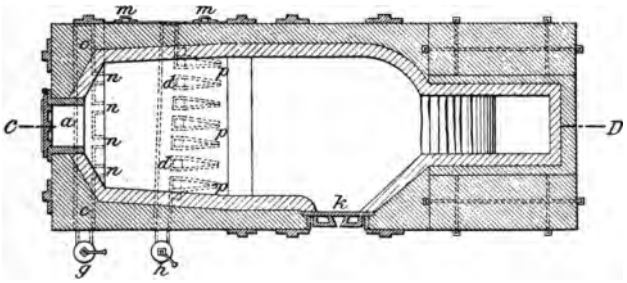


FIG. 90. PUDDLING FURNACE DESIGNED BY ANTON MUELLER.

tained in the furnace proper. An inclined plane *ll*, provided with perforations, is shown in Fig. 91, being used in place of a grate. The use of a grate of this character allows the gasification of almost dusty peat. The lower blast passes from the main *c* through four tuyeres *nn* into the wind box *o*. Fuel is charged through a door *a*. The upper blast is discharged from a blower through a heating box into the pipe *d* and thence through seven tuyeres *pp* to the hearth.

The temperature of the blast is about 100° Cent. In a later construction of this furnace the blast is heated to about 200° Cent., by means of tubes arranged in a boiler furnace. At one side of the furnace is a slit *bb* for removing ashes and slag. This is closed by the door *mm*. The lower and upper blasts are regulated by the valves *g* and *h* in Fig. 90, which also shows the working door *k*.

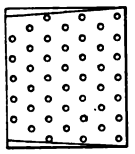


FIG. 91. DETAIL OF GRATE.

The puddling furnace of ordinary construction is shown in Figs. 92, 93 and 94. Fig. 92 is a section on the line *FG* of Fig. 93. Fig. 93 is a section on the line *AB* of Fig. 92 and Fig. 94 is a section on the line *CDE* of Fig. 92. In this furnace the gas enters the wind box *aa*, to which is attached the reservoir *b* for the upper blast, which is heated in the heater *ee* built into the stack. The heater comprises two square boxes *dd'*, which communicate with each

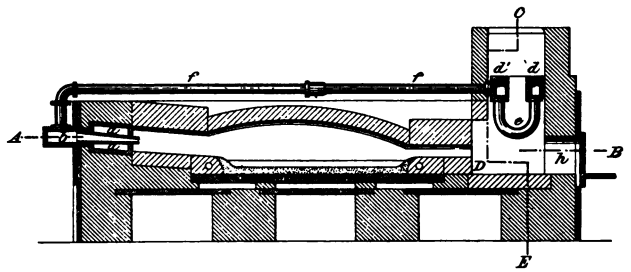


FIG. 92.

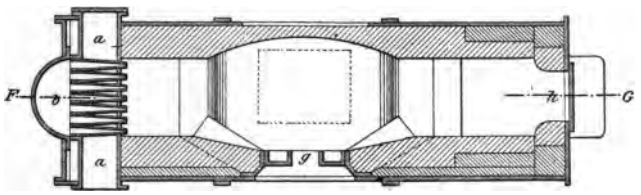


FIG. 93. AN ORDINARY PUDDLING FURNACE.

other through five elbows *ee*. The cold blast enters *d* through the pipe *cc*, and from *d'* the hot blast passes through *ff* to *b*. The pig iron is preheated in the arched doorway *h*. A working door is shown at *g*, Fig. 93.

A regenerative puddling furnace is shown in Fig. 95, which is a front view with a subterranean section. Fig. 96 is a cross section of the furnace on the line *ABCD* of Fig. 97, which is a plan section on the line *LM*, Fig. 96. The gas enters through the valve *b* into

the reversing valve *b'*. At *q* is a regulating lever for the valve *b*. The air reversing valve is directly behind *b'* and the respective valves are regulated by the levers *p* and *r*. The lever *s* regulates the draft, and, by this arrangement, the workman is in perfect control of the operations. The gas channels are shown at *m* and *m'* in Fig. 95, while the air channels are at *n* and *n'* in the same view, and *o* is a communication to the stack. The hearth of the furnace *dd*, Figs. 96 and 97, is of ordinary construction and consists of solid cast-iron plates which are protected from rapid and early burning by a suitable arrangement of water cooling. The water flows from coolers to reservoirs provided at each side, from which it can be discharged. The water vapors preserve the plates

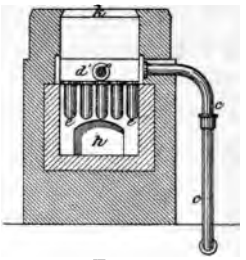


FIG. 94.
PUDDLING FURNACE.

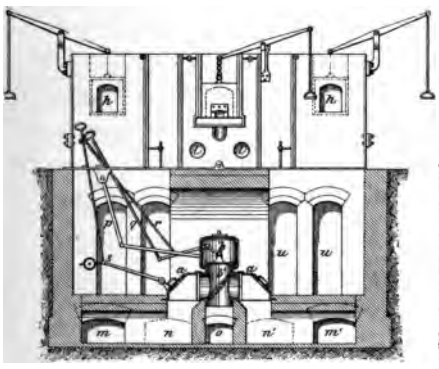


FIG. 95.

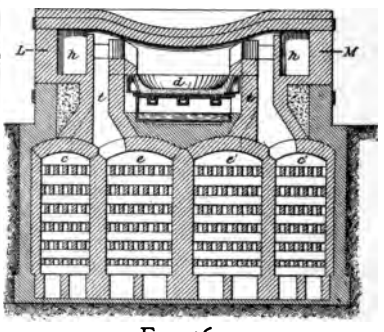


FIG. 96.

REGENERATIVE PUDDLING FURNACE.

of the hearth. They enter the pipes *ii*, Fig. 95, and escape through flues *kk*, Fig. 97, into the atmosphere. The preheaters for the billets are shown at *hh* in all three views. The billets are heated here to redness before being charged to the puddling hearth *dd*. The air channels are shown at *fff*, Fig. 97, and the gas channels at *gg*. Cleaning openings for the valve boxes are at *aaa*, Fig. 95, and at *tt'*, Fig. 96, are channels from and to the regenerators, *uu* in Fig. 98 being the "doors" to the latter.

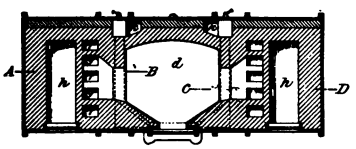


FIG. 97. REGENERATIVE PUDDLING FURNACE.

In Figs. 98 and 99 is shown one-half of a symmetrically-built

welding furnace installed at the Vulcan Works near Settin, Germany. Fig. 98 is a section on the line *CD* of Fig. 99, while Fig. 99 is a section on the line *AB* of Fig. 98. The regenerators are shown at *e* and *e'*, *e* being the air regenerator and *e'* the gas regenerator.

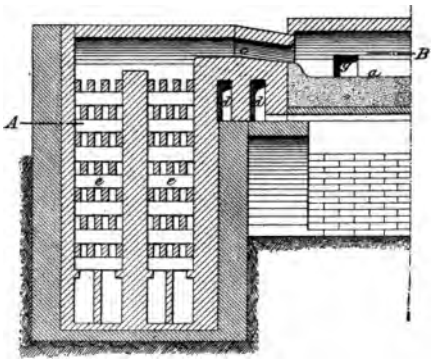


FIG. 98. WELDING FURNACE.

The hearth is at *a* and the flue at *c*. The working doors are two in number, one being shown at *b*. The charge is gradually moved from the cooler to the hotter parts of the hearth. Opposite the doors *b* are provided openings *g* in the back wall for the purpose of

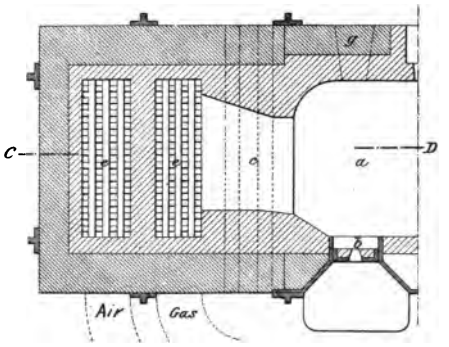


FIG. 99. WELDING FURNACE AT VULCAN IRON WORKS.

making possible the welding of long shafts. At *dd*, Fig. 98, are air channels for cooling the flues.

The Siemens regenerative puddling furnaces were somewhat modified by Bonehill. This modified arrangement is shown in Figs. 100, 101 and 102, Fig. 100 being a section on the line *MNOP* of Fig. 102, Fig. 101 a section on the line *HJKL* of Fig. 100, and Fig.

102 a plan section on the line, *ABCDEFGRS* of Fig. 100. This arrangement consists of a furnace *a*, Fig. 102, two twin gas producers *b*, Figs. 100 and 102, and two regenerators *c*, Figs. 100 and 101. The gases go through the valve *d*, Fig. 101, to the reservoir *e*, the two spaces of each group being connected by a channel *f*, Fig. 100. Each reservoir contains a valve *g*, Figs. 100 and 101. The two valves *g* are alternately opened and closed, so that the gases

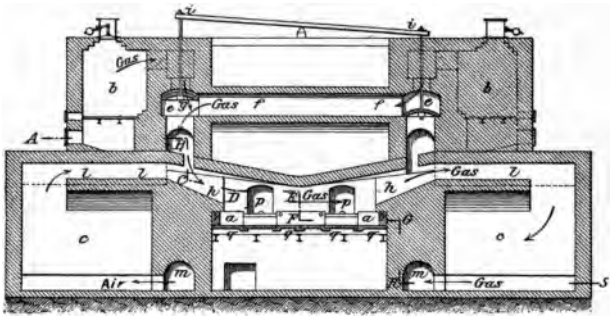


FIG. 100.

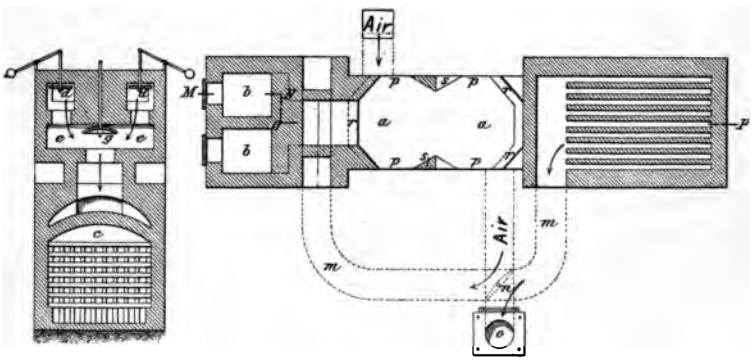


FIG. 101. FIG. 102.

MODIFIED SIEMENS REGENERATIVE FURNACE.

alternately enter one of the two combustion chambers *hh*, Fig. 100, provided at the ends of the furnace. A double lever *i* connects the valves *gg* and insures their alternate action. Two channels *ll*, Fig. 100, from the regenerators *cc* enter these two combustion chambers. The regenerators *cc* are connected by the channel *m* Fig. 102, and can be put in communication by means of a valve *n* either with the air channels provided under the furnace or the stack. The valves *d* can be opened and closed independently of one another.

E. & P. Martin in Sireul were the first to use the regenerative puddling furnace for the manufacture of steel. A furnace of this type is shown in Figs. 103, 104 and 105. In its construction hearth plates and regenerators are cooled by channels *ss*, Fig. 104, which communicate with the atmosphere and end in slits *r*, Fig. 105. In Fig. 105, *nnn* are three doors in the front of the furnace for charging heavy pieces and also for the purpose of repairing the hearth. In the same figure *ooo* are also used for charging. Cast-iron hoppers *aa*, Figs. 103 and 104, are surrounded by heavy clay pipes *qq*,

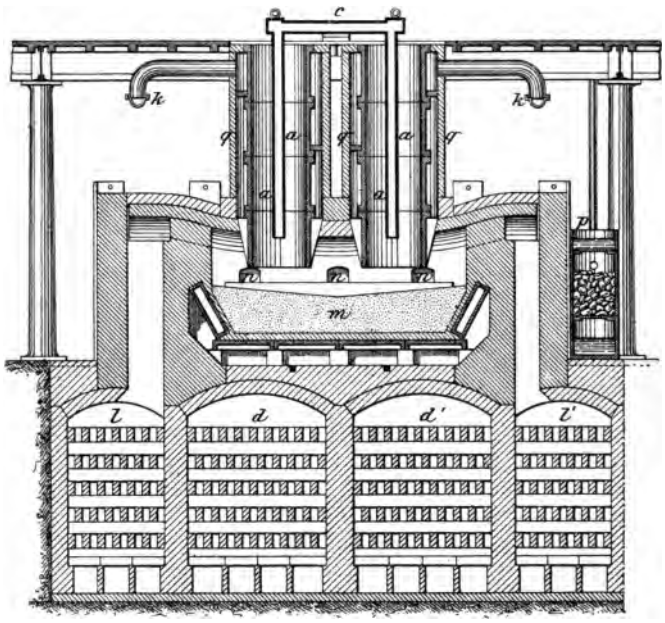


FIG. 103. REGENERATIVE PUDDLING FURNACE FOR STEEL MANUFACTURE.

the latter being placed in communication through pipes *kk* with the furnace, in order to effect a circulation of heat. The flame can also play in the space between *aa* and *qq*, thereby heating the iron contained in *aa* to redness. From the gas mains a wrought-iron pipe branching at *c*, Figs. 103 and 104, to the right and left, and reaching nearly to the bottom of the hoppers, carries the reducing gas to the metal. In order to make this gas current continuous a steam jet is employed at the point where the gas leaves the main *g*, Fig. 104, whence the gas and steam together enter a small condenser

p, Fig. 103, which is filled with water and coke, whereby the steam is condensed and the gas purified. The gas reversing valve is shown at *e* and the air reversing valve at *e'*, Fig. 104. The channel *h*, Fig. 104, leads to the chimney. In Fig. 103 *l* and *l'* are the gas generators and *d* and *d'* the air regenerators.

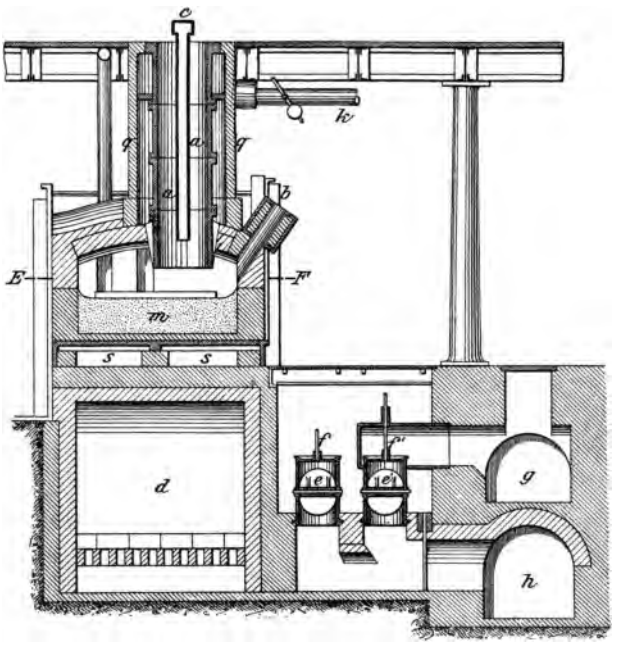


FIG. 104.

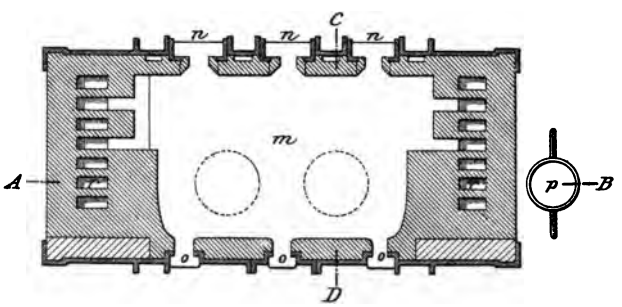


FIG. 105. REGENERATIVE PUDDLING FURNACE FOR STEEL MANUFACTURE.

The "chemical" Siemens steel furnace is shown in Figs. 106 to 110. The gas from the producer *B* goes directly to the hearth *E*, Fig. 106. Instead of air, a portion of the products of combustion

in a highly heated state is used in the producer for gasification, in accordance with the equation $C + CO_2 = 2CO$. The regenerators for the air are at *AA'*, Figs. 106 and 107. At *FF'*, Figs. 106 and

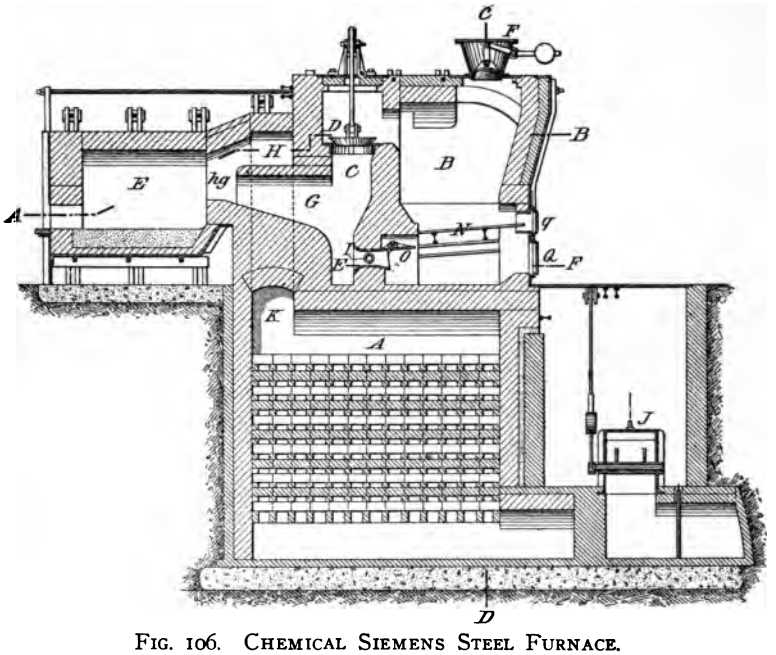


FIG. 106. CHEMICAL SIEMENS STEEL FURNACE.

107, are the coal hoppers, *N* and *N'* being the grates. The gas passes from the producer through channels *cc'*, its flow being regulated by the valves *DD'*, Fig. 109. These are so arranged that by opening one the other is closed, the gas being led to the hearth through the openings *GG'*, Figs. 106 and 107. The air for combustion enters at *HH*, Figs. 106 and 108, communicating through the channels *KK*, Fig. 106, with the regenerator *AA'*. Steam jet blowers built into the openings *LL* are shown at *I*, Figs. 106 and 110. These blowers transfer the products of combustion from the furnace to the producer. In Fig. 106 at *J* is shown an air reversing valve, which also serves for the waste gases, *OO* in the same figure being valves for interrupting the action of the furnace and the producer, these valves being used for the waste gases. The valves are connected to the lever of the valves *DD'*, and, by opening *D* and *D'*, respectively, *O* and *O'*, respectively, are closed. *QQ* are cleaning holes for the grate.

The operation of this furnace is as follows:

Gas from the producer *B* passes through the channel *C*, the valve *D* and the opening *G* to the combustion space *hg*, Figs. 106 and 108. The air to support combustion reaches this space through the regenerator *A*, the channel *K* and opening *H* and burns the gas. The flame passes through *E* and the waste gases escape partly through the other combustion space *hg*, the passages *H* and *K* and go through the regenerator *A* and the valve *J* to the stack. A portion of the gas is drawn downwards through the opening *G* by the blower *I* and passes through *L* to the producer. The gases are here converted into combustible gases. At certain intervals the direction of the flame in the furnace is reversed by means of the valves *DD'* and the reversing valve *J*. In order to deliver the necessary air for starting the plant, an auxiliary steam jet blower is provided under the grate. Since this furnace was introduced several changes have been made regarding the arrangement and connection of the producer.

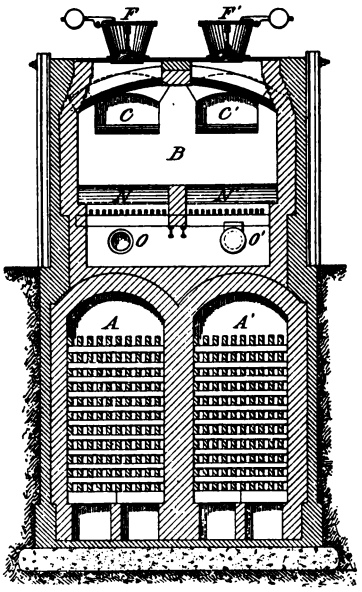


FIG. 107. SIEMENS FURNACE.

Fig. 111 shows an American open-hearth furnace with regenerators built under the end of the furnaces. Fig. 112 shows a similar furnace with regenerators under the charging platform.

In Fig. 113 is illustrated a pit furnace designed by Victor Beu-

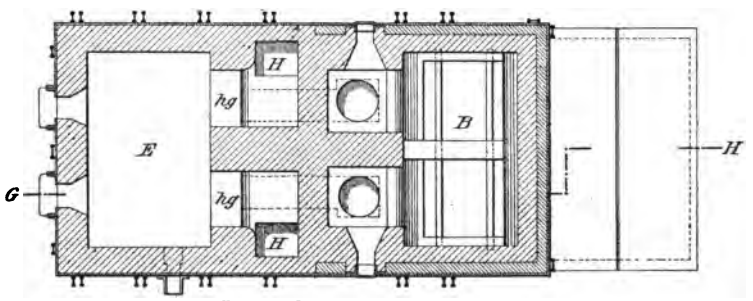


FIG. 108. SIEMENS FURNACE.

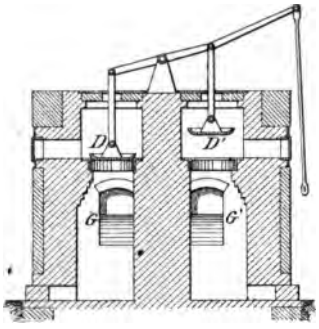


FIG. 109. DETAIL OF VALVES *D* IN FIG. 106.

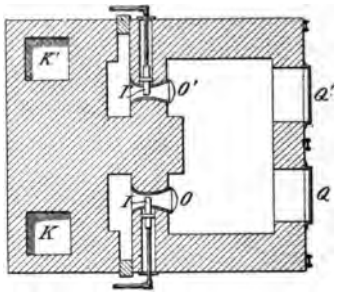


FIG. 110. DETAIL OF VALVES *I* IN FIG. 106.

THE "CHEMICAL" SIEMENS FURNACE.

thner. Each furnace comprises four pits, 6 ft. by 5 ft., and is provided with recuperators for air and gas. Each pit has four valves on each side. Altogether there are 32 valves arranged in four parallel rows. The two outer rows lead to the flues. One of the inner rows leads to the gas and the other to the air channels.

In Fig. 114 is shown a pit arrangement in a rolling mill. This furnace is fired with natural gas, but it can be easily transformed so as to utilize producer gas. A heating furnace used for the steel foundry at Neuberg, in Styria, is shown in Fig. 115. In this furnace the entire floor can be drawn out for charging. A sand sea!

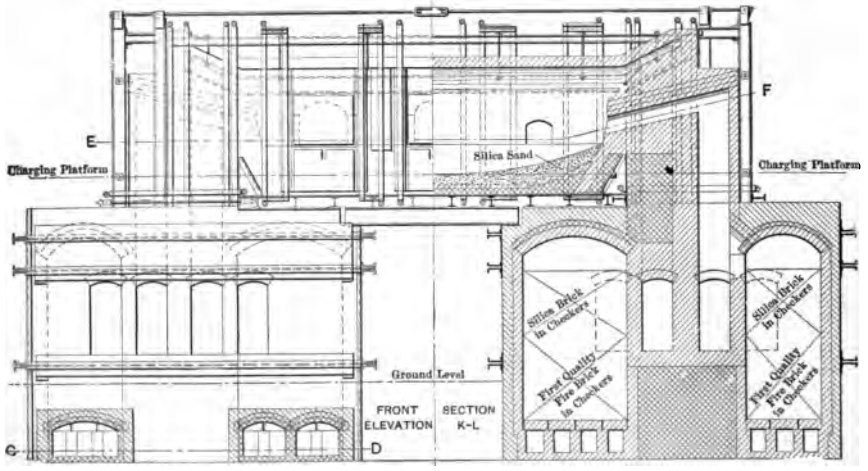


FIG. 111. AMERICAN OPEN-HEARTH FURNACE WITH REGENERATORS UNDER FURNACE.

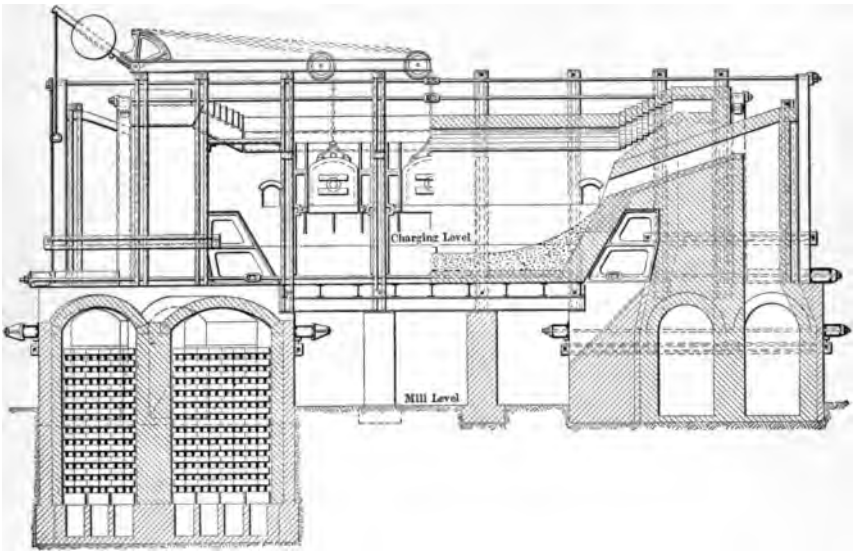


FIG. 112. AMERICAN OPEN-HEARTH FURNACE WITH REGENERATORS UNDER CHARGING PLATFORM.

is used between the floor and the side walls, as shown in the detail drawing.

The Waldburger continuous heating furnace is illustrated in Fig. 116. This furnace is designed for gas fuel and has an air regen-

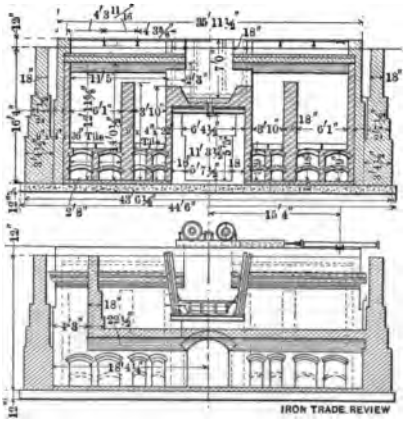


FIG. 113. PIT FURNACE DESIGNED BY VICTOR BEUTHNER.

erating chamber in the roof. It also provides for the gases of combustion to circulate below the material to be heated, as well as

above. By this construction the slag is prevented from clogging the spaces between the benches and is kept in such a condition that it will flow down the sloping bottom into the cinder pocket, from

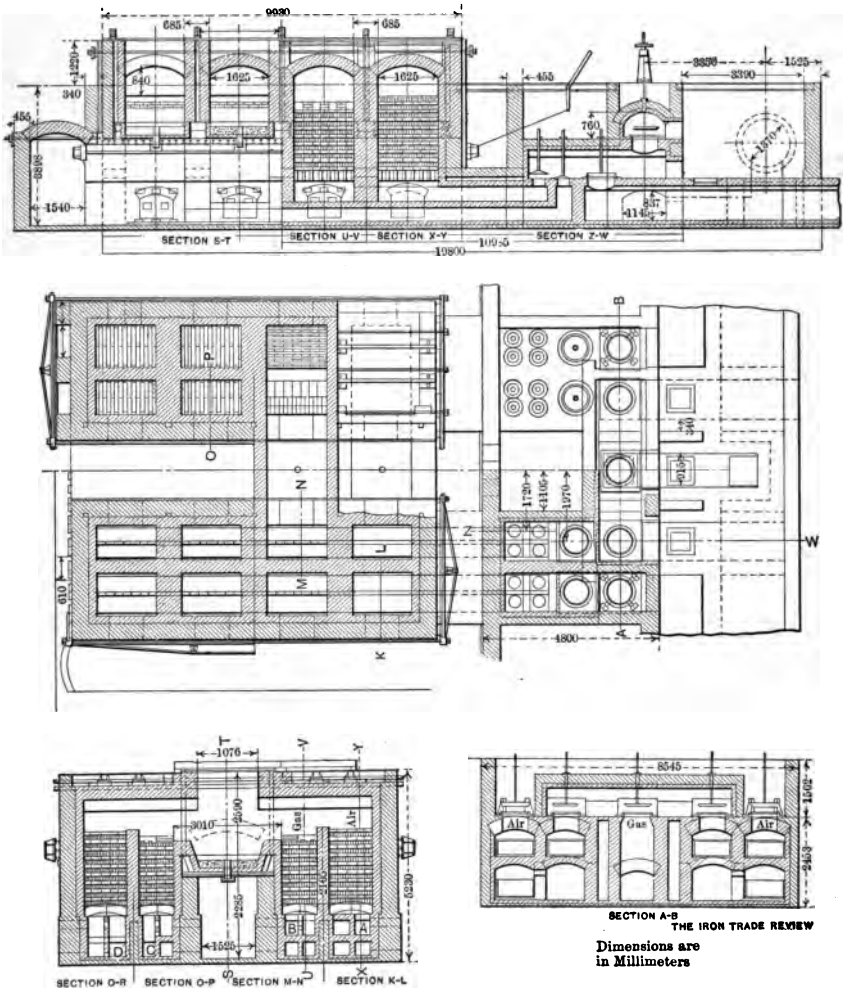


FIG. 114. PIT FURNACE FOR ROLLING MILL.

which it can be tapped. The heating operation is rendered even and rapid by reason of the combustion of the gas above and below the hearth, especially when large sized blooms or slabs are heated, which results in a greater output and a more successful operation of the furnace.

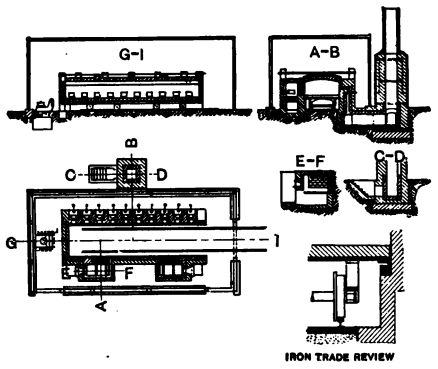


FIG. 115. HEATING FURNACE FOR STYRIAN STEEL FOUNDRY.

The Forter-Miller Engineering Company has constructed a gas-fired continuous billet furnace with an air heating chamber in the roof. This construction is shown in Fig. 117. The rear or discharging end is arched upwardly and heated air unites with the gas at the top immediately in front of the gas inlet. The receiving hearth at the rear end provides for the removal of cold spots, the discharge door being immediately in the rear. The billets travel directly through the furnace and out upon tables or buggies arranged along the rear.

A movable bottom continuous heating furnace with an improved lifting bottom is shown in Fig. 118. It is operated by an engine, connecting rods and lifting levers, provided with supporting rollers.

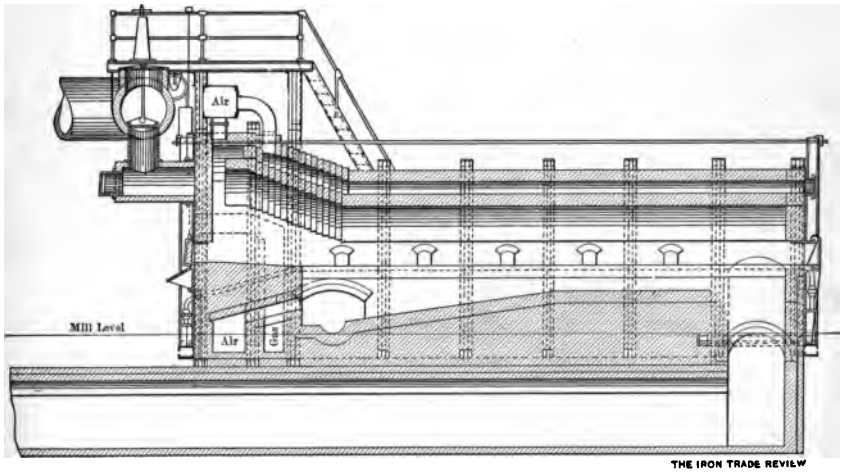


FIG. 116. WALDBURGER CONTINUOUS HEATING FURNACE.

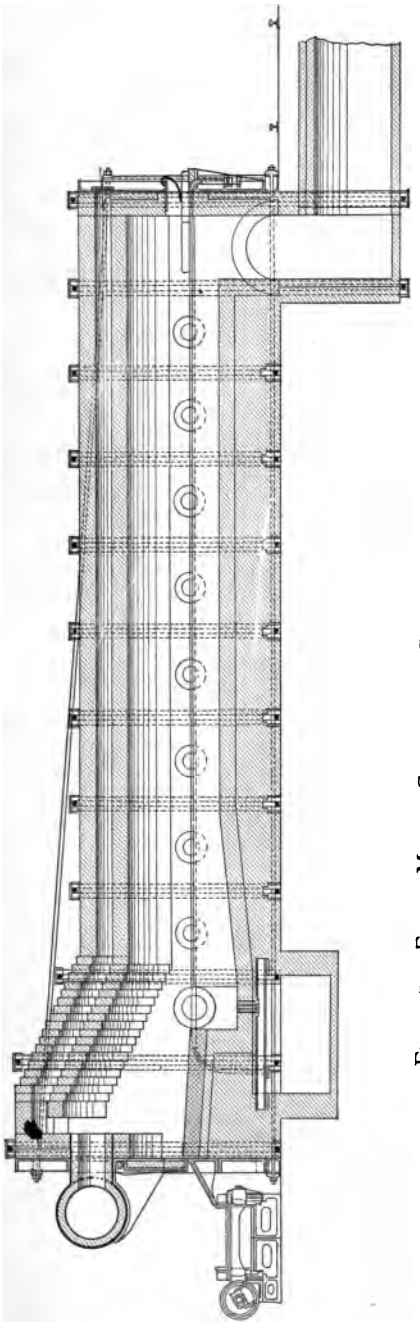


FIG. 117. FORTER-MILLER CONTINUOUS GAS-FIRED BILLET HEATING FURNACE.

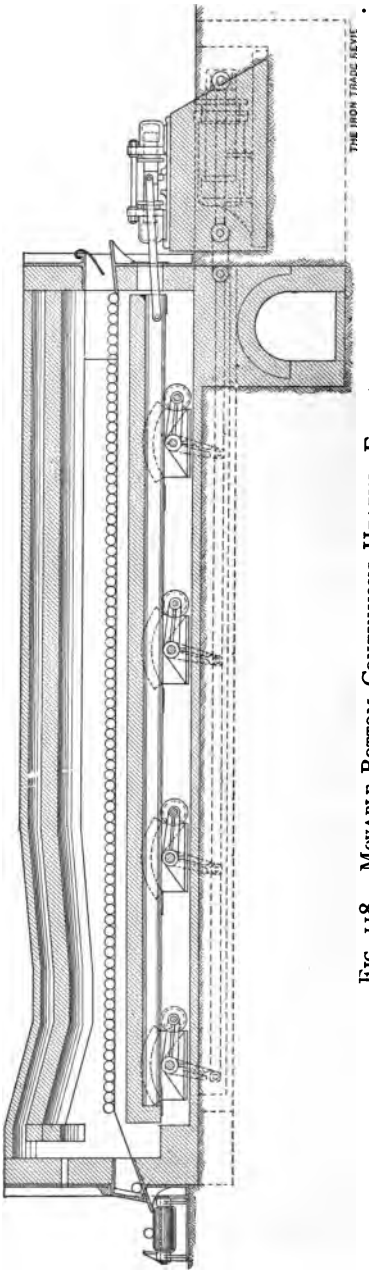


FIG. 118. MOVABLE BOTTOM CONTINUOUS HEATING FURNACE.

The operation of this furnace is practically automatic. It discharges one billet at a time and may be arranged as to speed to suit the receiving or discharging capacity. It is usually equipped with

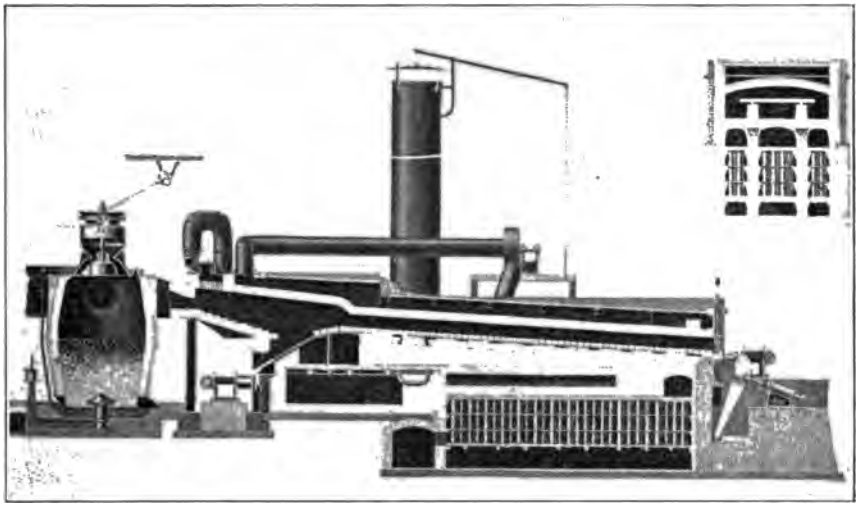


FIG. 119. MORGAN CONTINUOUS GRAVITY DISCHARGE BILLET HEATING FURNACE.

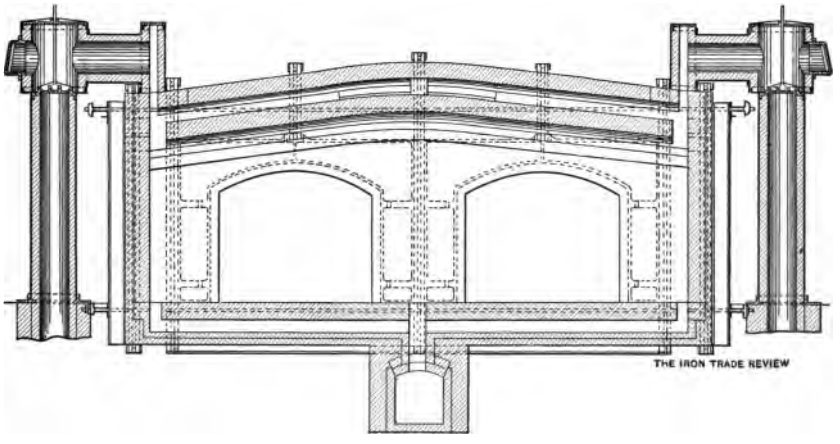


FIG. 120. GAS-FIRED ANNEALING FURNACE.

a train of service rollers and automatic doors. The well-known Morgan continuous gravity discharge billet heating furnace and continuous gas producer is shown in Fig. 119, Fig. 120 is a gas-fired annealing furnace, while Fig. 121 is a type especially adapted for annealing malleable castings. In the latter construction, which

can be built in single units, or in multiple, the waste heat is utilized for maintaining a hot furnace bottom. Fig. 122 illustrates the construction of a sheet and pair furnace, while Fig. 123 shows a similar

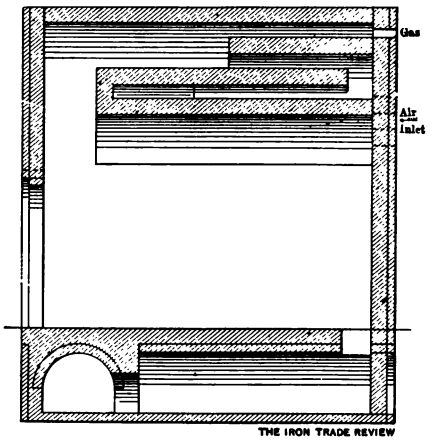


FIG. 121. ANNEALING FURNACE FOR MALLEABLE CASTINGS.

furnace with gas and air ports. This latter is so constructed that the pre-heated air enters the furnace through the parts alongside of the gas ports. A welding furnace constructed by Lagergren is shown in Fig. 124. This furnace is about 18 feet long and 4 feet wide. The height of the arch is about 18 inches. It consumes about 260 pounds of coal per hour and has a capacity of 1,200

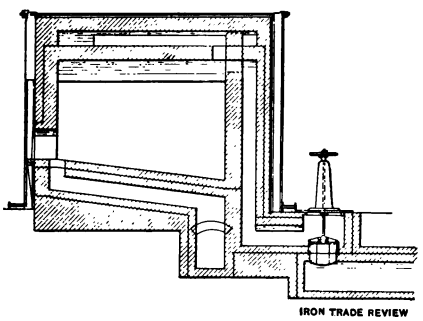


FIG. 122. SHEET AND PAIR FURNACE.

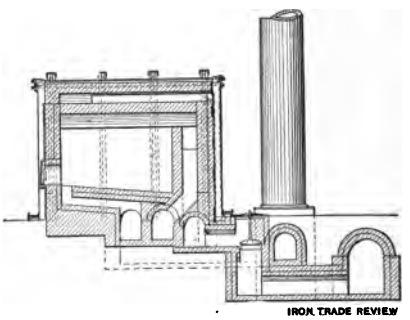


FIG. 123. SHEET AND PAIR FURNACE WITH GAS AND AIR PORTS.

pounds of Lancashire iron. Gustav Uhr's welding furnace, which is used in Sweden in many iron works, is shown in Fig. 125. This is built to use the soft coal producer gas and has a capacity of 1.75

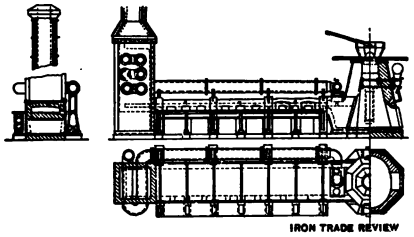


FIG. 124. LAGERGREN WELDING FURNACE.

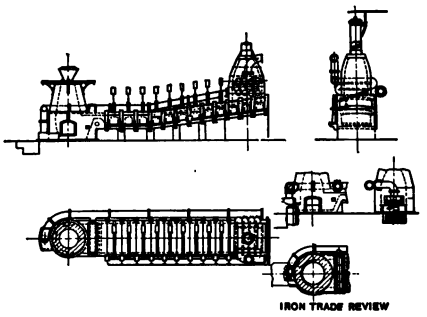


FIG. 125. WELDING FURNACE DESIGNED BY GUSTAV UHR.

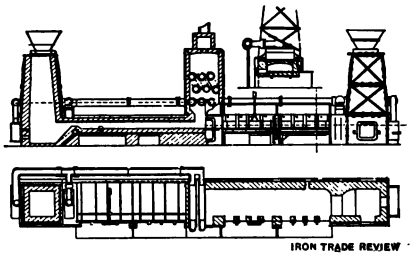


FIG. 126. UHR'S DOUBLE WELDING FURNACE.

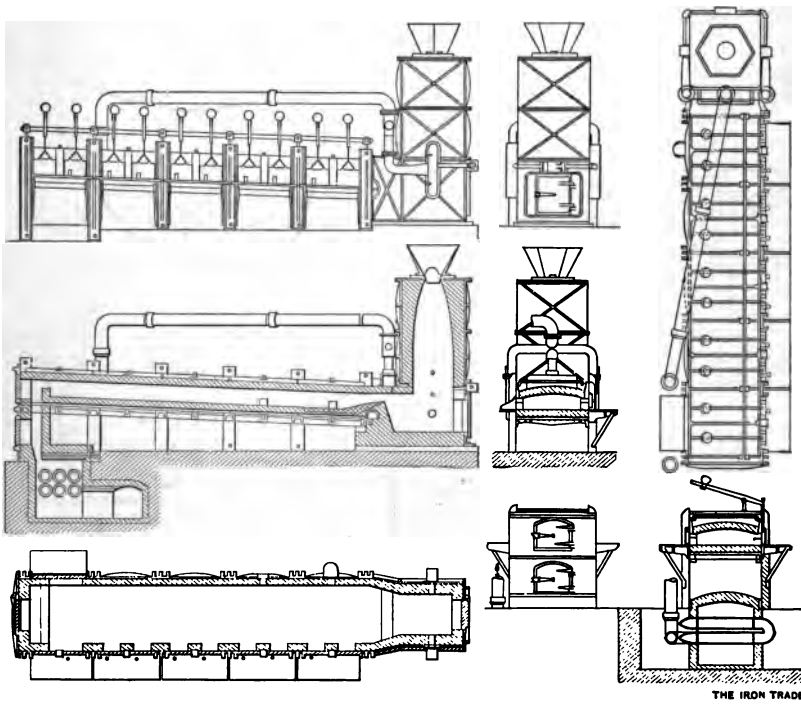


FIG. 127. SWEDISH WIRE FURNACE.

tons. The furnace is 23 feet long, 4 feet wide and 5 feet high. It consumes 290 pounds of coal per hour. Fig. 126 shows Uhr's double welding furnace, which is provided with one common heating apparatus.

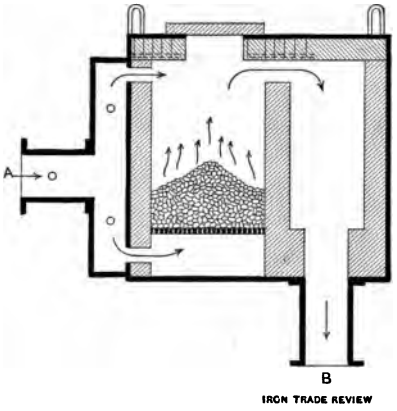


FIG. 128. FURNACE FOR FOUNDRY ROOM.

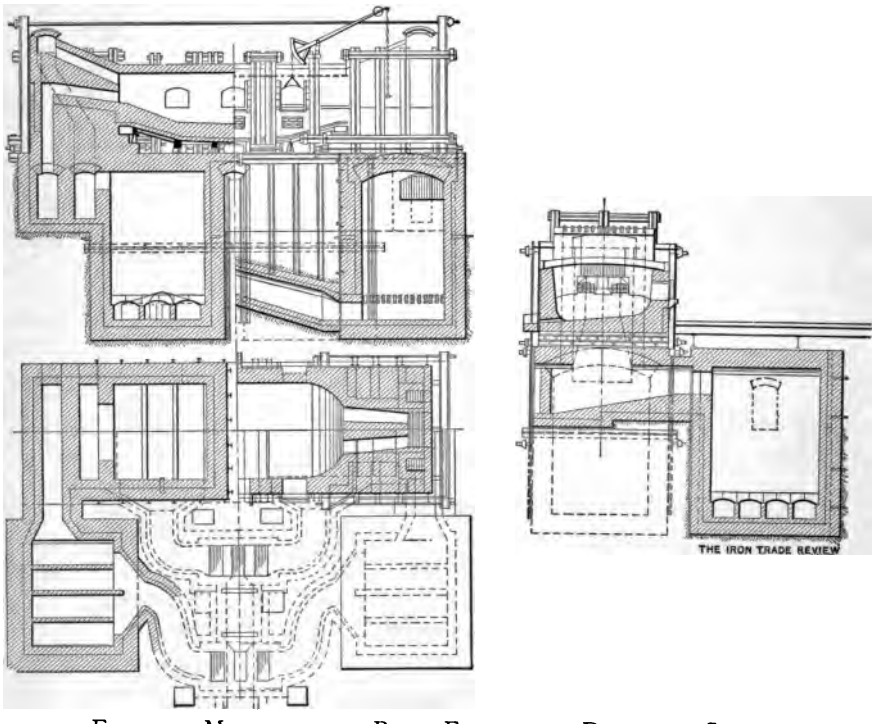


FIG. 129. MARTIN 30-TON BASIC FURNACE AT DONAWITZ, STYRIA.

The welding furnace which is used in Swedish wire plants is shown in Fig. 127. Detailed information regarding all of these Swedish furnaces may be found in *Jernkontorets Annaler*. A fur-

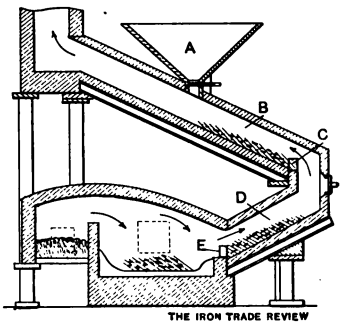


FIG. 130. KENT'S PUDDLING FURNACE.

nace for a foundry drying room is shown in Fig. 128. This is a direct-fired furnace, which can be transformed into a gas producer by the simple process of making the fuel bed deeper. The

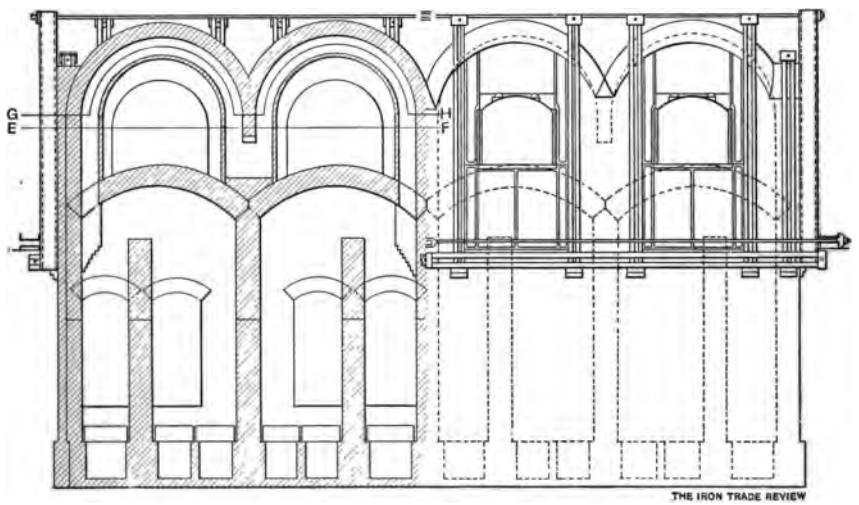


FIG. 131. CONTINUOUS REGENERATIVE MUFFLE FURNACE.

cold air enters at *A* and the hot air and products of combustion leave at *B*. Fig. 129 illustrates a 30-ton basic Martin furnace from Donawitz, Styria. Fig. 130 illustrates Kent's puddling furnace, which can easily be transformed for gas firing. Metal shavings, which are highly heated by the flames leaving the furnace before they reach

the hearth, are used as a charge. The charges go from the hopper *A* to the inclined plane *B*, and after removing the block *C* to the inclined plane *D*. After removing the block *E*, the metal goes to

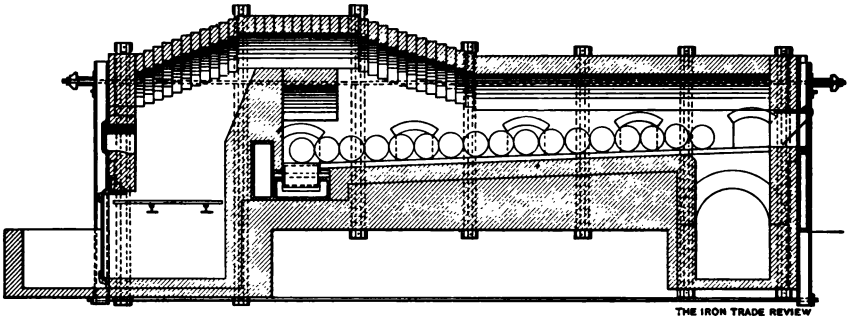


FIG. 132. MULTIPLE ANNEALING FURNACE.

the hearth proper. The charge can also be mixed with charcoal, in which case it will absorb carbon on the planes *B* and *D*. In connection with metallurgical and metal work, the following furnaces are frequently used. The continuous regenerative muffle furnace,

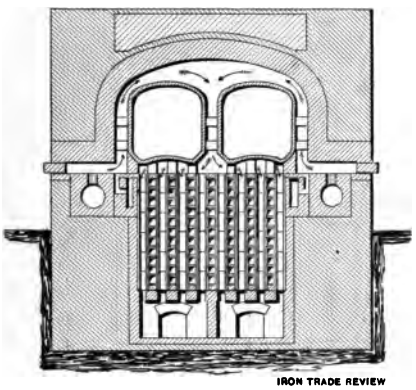


FIG. 133. DOUBLE MUFFLE FURNACE WITH RECUPERATORS.

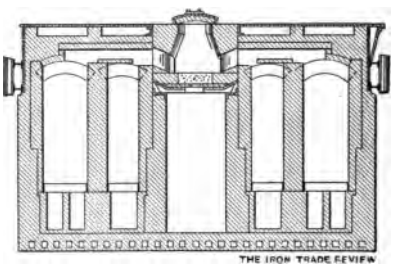


FIG. 134. SIMPLE TYPE OF CRUCIBLE FURNACE.

shown in Fig. 131, is especially adapted to perfect operation with all kinds of porcelain enameled ware, bathtubs, basins, zincs, etc. The combination with the regenerators insures a constant, regular heat and uniform exposure throughout, resulting in a high average of perfect output and a minimum of seconds or loss. This furnace, which is adapted for continuous and economical operation, is built with single or multiple chambers to suit the character of the work.

The multiple annealing furnace shown in Fig. 132 embodies a novel arrangement of inclined tracks, doors, etc., and the circulation of the gases of combustion is such as to gradually heat the contents. The rear baffle wall is arched over and provides a protecting coping for the last few cylinders and rollers. The roof is arched above and sloped at the front and back, giving the best heating effect. The runways are of tile set on edge with intervening spaces and extend across the flue to the charging door. The special feature of advantage is that the cylinders are constantly revolved toward the fire box and are thus gradually subjected to an increasing degree of heat throughout their travel. Fig. 133 shows a double muffle furnace with recuperator and Fig. 134 a simple type of crucible furnace.

CHAPTER VII.

PRODUCER GAS-FIRED FURNACES IN THE LIME AND CEMENT INDUSTRIES.

The first extensive uses of producer gas in the arts related to metallurgical purposes, especially in connection with the manufacture of steel in the open-hearth furnace, utilizing the regenerative system of Siemens. More recently the gas producer has been extensively used in connection with the production of power, the lean gas

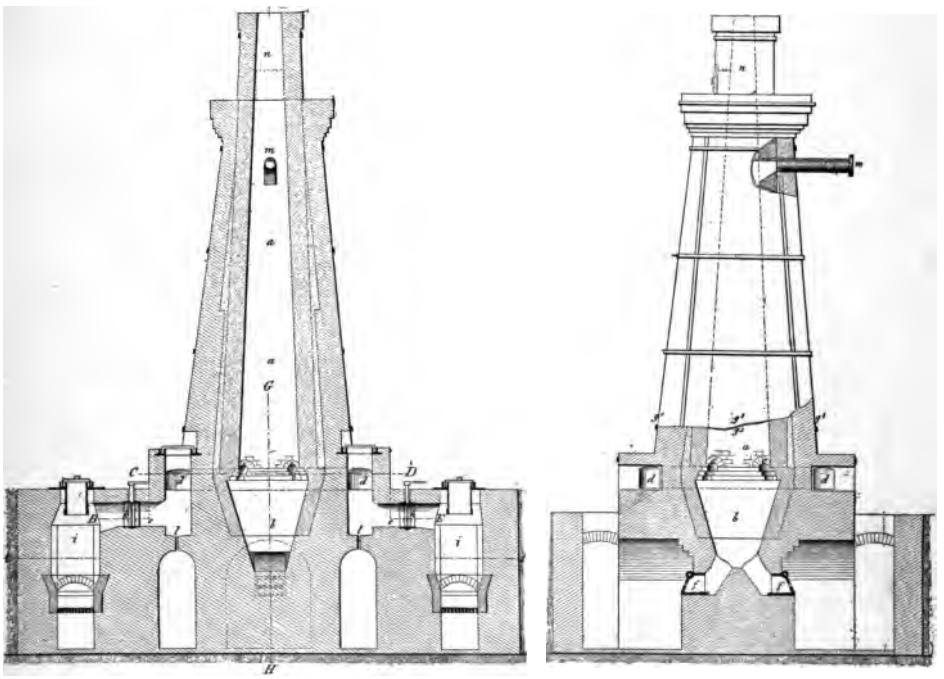


FIG. 135. VERTICAL SECTIONS OF THE STEINMANN GAS-FIRED LIME KILN.

being used in internal combustion engines with success, and this department of industrial gas utilization seems destined to wide development. It is advantageous, however, to use producer gas for many operations involving the development of heat, and among these may be considered the calcining of lime and cement.

By using producer gas for burning lime an economy of 25 to 35 per cent. of fuel is effected, as compared with direct-fired kilns. Another advantage of gas firing is the production of a purer product as the lime does not come in contact with the fuel, and hence remains free from ash.

The first successful producer gas-fired lime kiln was built by Steinmann. This furnace, which is shown in Figs. 135 and 136, can be

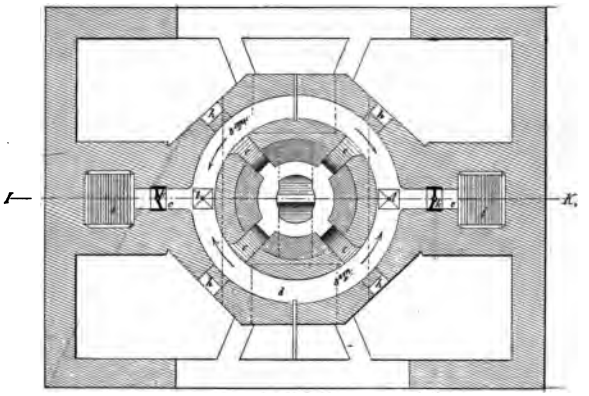


FIG. 136. SECTION PLAN OF THE STEINMANN KILN.

used either for the burning of lime only or also for the simultaneous production of carbon dioxide. If the furnace is to be used alternately for both purposes, its upper part is provided with a pipe *m* for carbon dioxide and besides with a top *n*, which is closed during the reclamation of carbon dioxide.

Either anthracite, bituminous coal or lignite may be used as fuel in this case.

The shaft *aa* is lined with fire-brick up to the top; *cc* are the gas tuyeres, these branching off from the ring-shaped gas channel *dd*, which is connected by means of channels *ee* with the two gas producers. The burnt lime is discharged through doors ranged at the bottom of the shaft, five circular openings, each having a diameter of about 10 inches and being fitted with small slides, being provided in each door. The air necessary for the combustion of the gases is allowed to enter through these openings and is preheated by passing through the burnt lime, the latter being simultaneously cooled thereby. The slides allow an exact regulation of the combustion and entire operation. A cleaning opening *hh* is provided opposite each of the four gas tuyeres, *cc*.

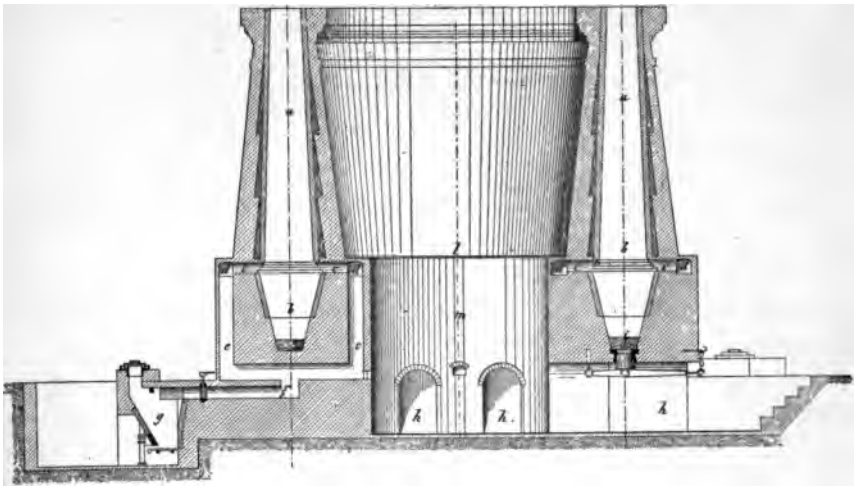


FIG. 137. VERTICAL SECTION OF THE BASTION KILN.

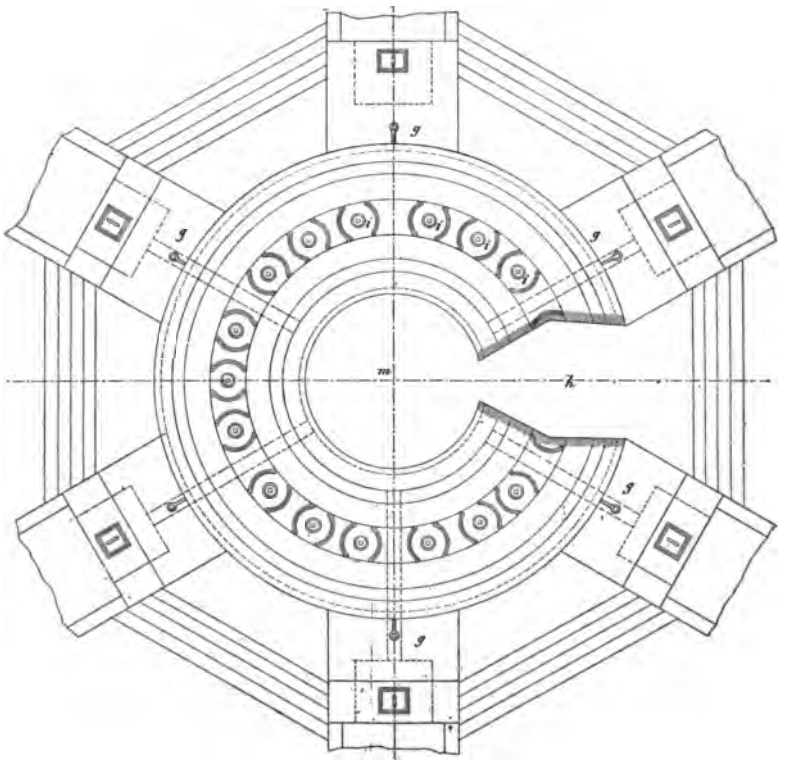


FIG. 138. PLAN OF THE BASTION KILN.

The valve *k*, provided in the gas main, allows the regulation of the quantity of gas admitted to the shaft. The tar contained in the gas is condensed at *ll*, and runs into the collecting chambers which are provided below and are closed air tight. Cleaning holes covered by water seal covers, which are marked in the plan view also with *ll*, are provided above the tar chambers. By means of the iron pipe *m* the

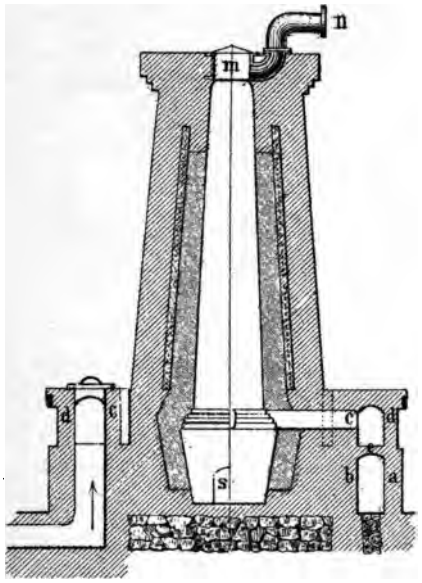


FIG. 139. THE HODECK KILN. VERTICAL SECTION.

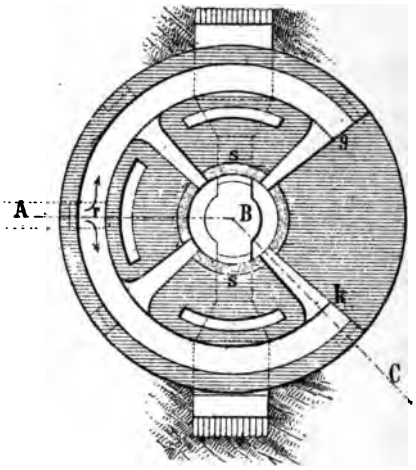


FIG. 140. HORIZONTAL SECTION OF HODECK KILN.

carbon dioxide is led through washers into the saturating vessels by means of suitable pumps provided between the washers and the saturators. The limestone is charged through the iron door *n*.

All parts of the kiln have to be preheated for at least seventy-two hours before starting operations. After sufficient preheating, the channels have to be cleaned from flue dust and ash before the charging of the limestone is started. The shaft is then loosely filled to about half of its height with pieces of limestone of about 10 inches in diameter.

After the shaft has been filled the wood-fire is started through the open discharging doors *ff;* the heat is gradually increased until the content of the shaft appears dark red in the zone of the four lowest peep-holes. The gas producer is then charged and started,

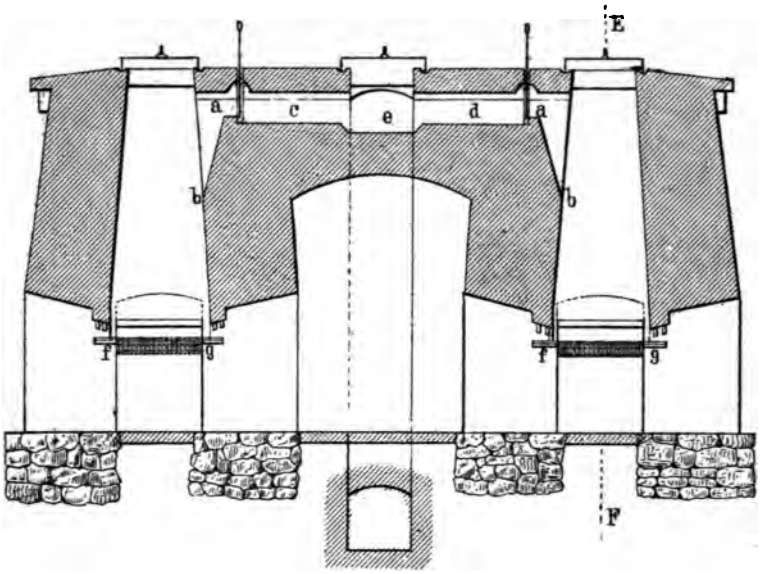


FIG. 141. VERTICAL SECTION OF HODECK PRODUCERS.

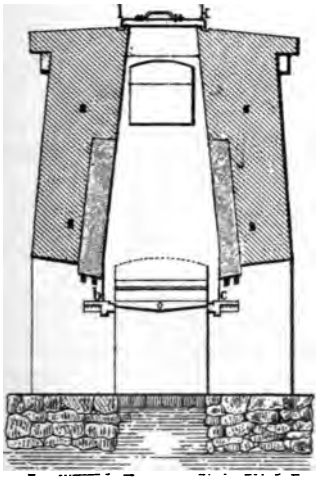


FIG. 142. TRANSVERSE SECTION OF HODECK PRODUCER.

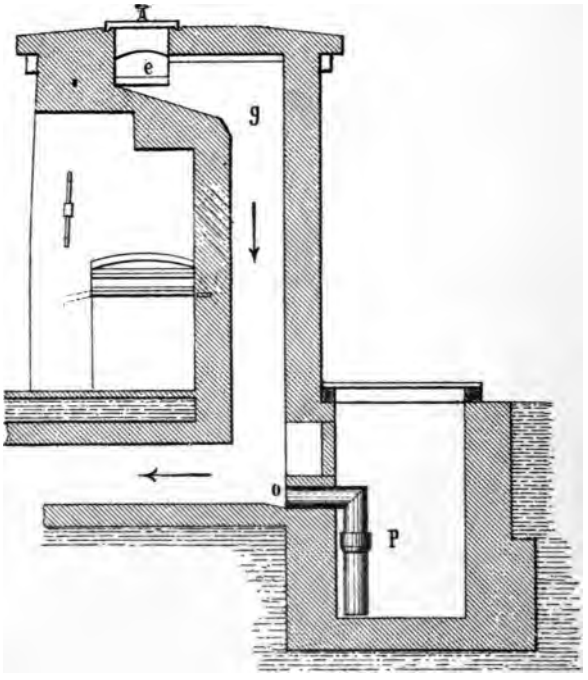


FIG. 143. PATH OF GASES IN HODECK SYSTEM.

and the gas-valve slightly opened and the gas is lighted. The first batch of lime is discharged two hours after the gas has been lighted, and, thereafter, in intervals of not less than one and a half and not more than three hours. After every discharge at the bottom, fresh limestone is charged through the top.

About every two months the channels, valves, tuyeres, etc., have to be cleaned, which is readily done by letting the coal burn down in the gas producers to a point near the incandescent layer, whereby an ignition of the tar is effected. Simultaneously the covers of the cleaning openings *hh,* leading to the tuyeres, and the covers above the tar chambers *ll* are removed, and then the tuyeres and ring channels cleaned.

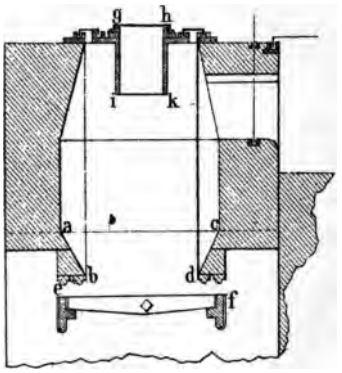


FIG. 144. HODECK PRODUCER.

Then everything is restored to the original condition, the gas producer rapidly recharged and the regular operation resumed. The ring channel is provided at two opposite sides with two horizon-

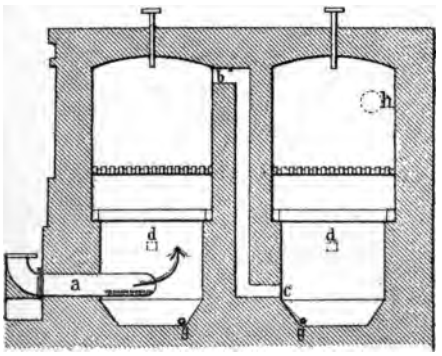


FIG. 145. HODECK GAS WASHER.

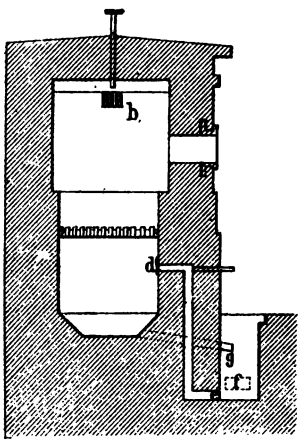


FIG. 146. SECTION OF HODECK WASHER.

tal movable slides, which are closed, if the furnace should have to be repaired on one side without shutting down the other side. According to the size of the kiln the operation can be stopped for four

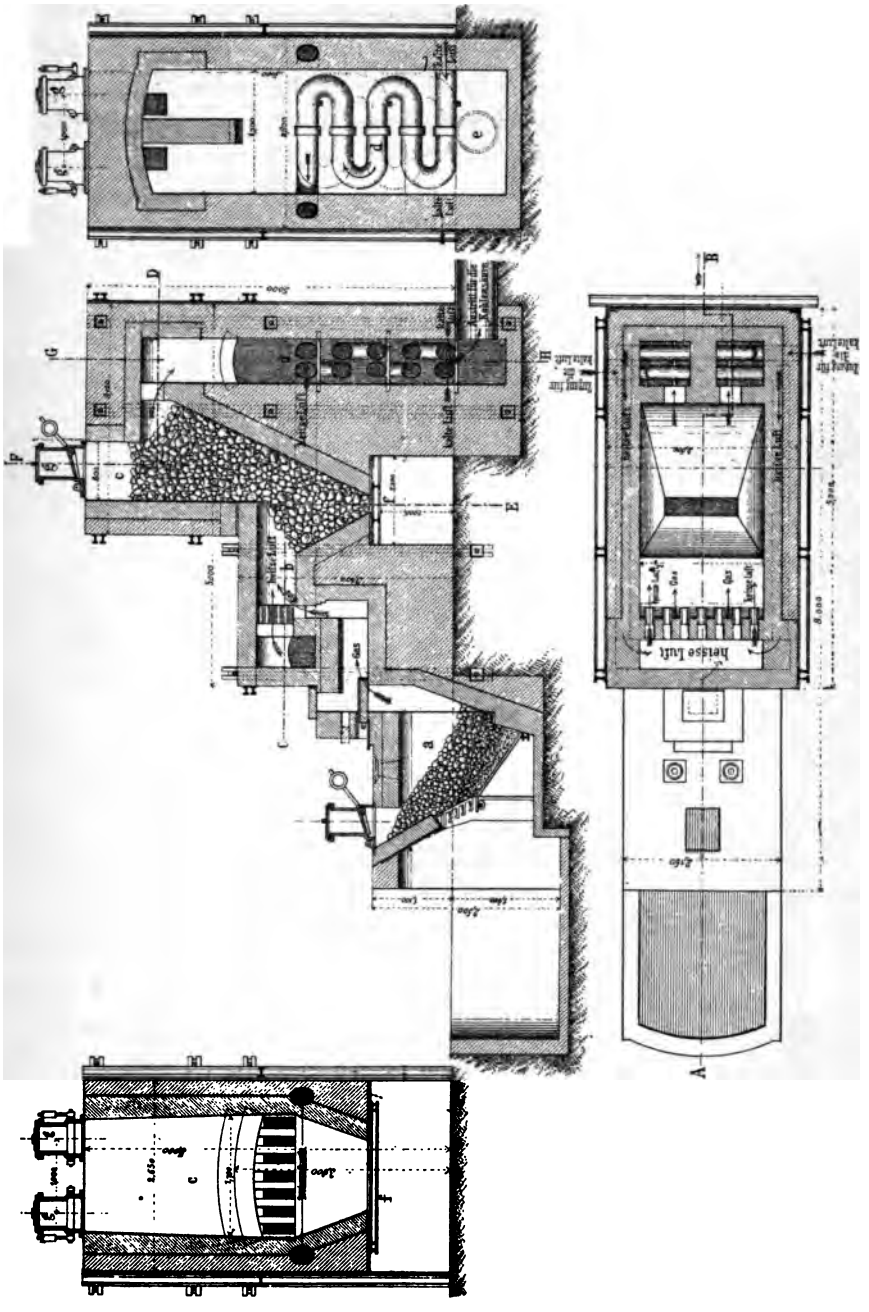


FIG. 147. THE PONSARD SYSTEM, SHOWING PRODUCER, KILN AND APPARATUS FOR PREHEATING THE AIR.

or six days without necessitating a regular preheating when operations are resumed. However, before shutting down, the gas producers have to be filled up to the top, the valves *kk* closed, as also the air inlets at *ff*, and the discharging doors themselves, and the top of the shaft covered.

As the flame in this kiln goes mainly vertically upward, there is a limit for the maximum admissible diameter, which was found by Steinmann at about five feet. A furnace with a larger diameter would contain unburned lime in the center. The length of the flame in the vertical direction, however, can be made from 25 to 28 feet. The furnace of five feet diameter and 28 feet of height produces ten tons of lime in 24 hours. For larger capacities these kilns have to be built with elliptical cross-sections. The first cost of such a furnace is not greater than the cost of a direct-fired kiln.

The Steinmann "Bastion" kiln, which is shown in Figs. 137 and 138, is intended for large capacities. A number of them are in successful operation, with a capacity of 35 tons per day, and have given much better results in fuel economy than direct-fired kilns. The construction of this type will be easily understood from the illustrations.

At *aa* is the shaft in which the limestone is burned; the burned material is collected in *bb; g* are the gas producers, of which there are six at the diameter of the furnace ring of 33 feet, *f* is the gas main, *e* the branch channels, *d* the ring channels, from which the tuyeres *c* branch off to the shaft; *i* are the discharge openings for the burned lime, which are closed by a highly-burned, cone-shaped fire-clay valve. The latter is more or less opened by means of a lever, whereby the admission of combustion air is regulated. The valve seats *i* are lined with iron castings. The combustion air absorbs the heat from the burned material contained in *d*, and forms a flame with the gas entering through the tuyeres.

Through the openings *hhh* the interior space *m* is reached, which can be used for storing the raw material, which, by proper elevating arrangements, can be lifted conveniently to the top of the shaft; *l* is a working platform. The hoppers *i* are separated from each other by saddle-shaped ribs, whereby the burned material is discharged uniformly to the left and right sides. These furnaces are started in practically the same manner as the kilns first described.

A gas-fired lime kiln, designed by Frueling, is about of the same

construction as the one shown in Fig. 135, the only difference being that the cross-section is rectangular instead of circular.

Hodeck has improved some of the features of the Steinmann kiln.

In the Hodeck kiln (Figs. 139–146) the gas channel is free at all sides, so as to facilitate cooling. It rests upon a channel, closed by arch *e*; this arch forms the sole, which is connected at *r* with the

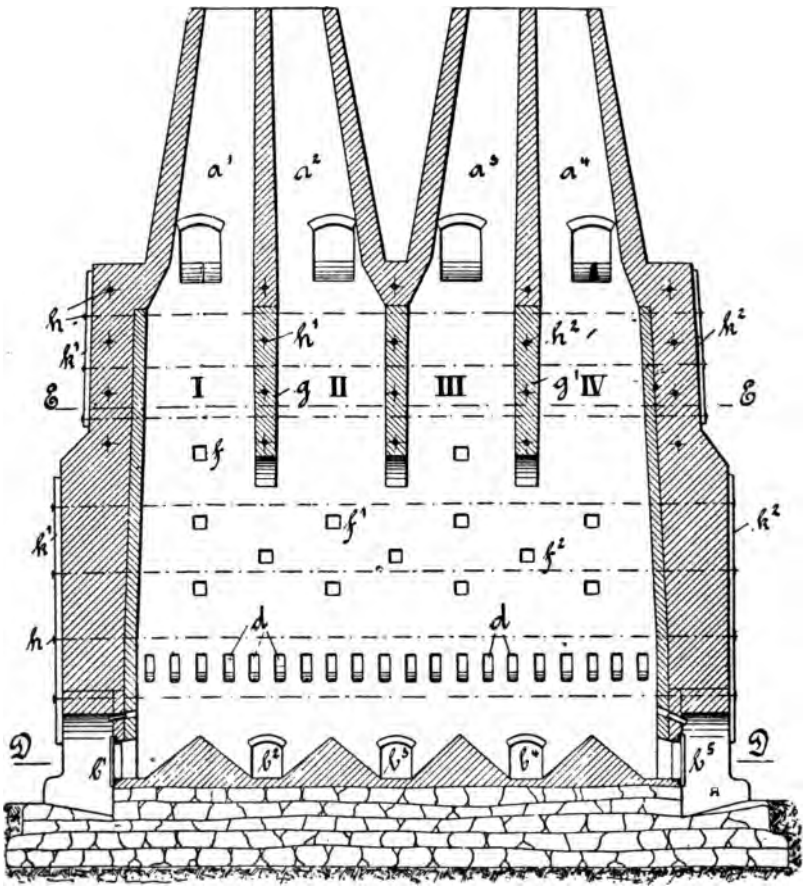


FIG. 148. THE ISSERLIS RECTANGULAR KILN.

gas channel. The ring channel does not go all around but stops at *g* and *k*. Beginning from the inlet opening *r* the sole of the channel rises towards *g* and *k* by about 9 inches, while the cover remains horizontal. This decrease of the cross-section is justified by the quantity of gas which decreases towards *g* and *k*. The lime is removed at *s*, the gas through *mn*.

The Ponsard lime kiln is characterized by its moderate height and by the use of highly preheated air for the combustion; the heating of the air being combined with the cooling of the carbon dioxide gas produced. As shown in Fig. 147, the apparatus consists of a gas producer *a*, the lime kiln proper, the front part *b* of which is used for the combustion of the producer gas, and the larger part *c* for the reception of the limestone. The apparatus *d*, for heating the air, is built of cast-iron tubes. This apparatus also effects the cooling of the carbon dioxide, which passes through pipe *e*. The mixture of gas and air takes place in a simply-constructed apparatus, in which the hot combustion air and the gas meet at right angles. The burned lime is discharged through *f*, and the limestone through the charging hopper *g*, which is provided with a cover resting in a water seal. The illustrations plainly show that only slight quantities of air can enter the shaft when a charge is made.

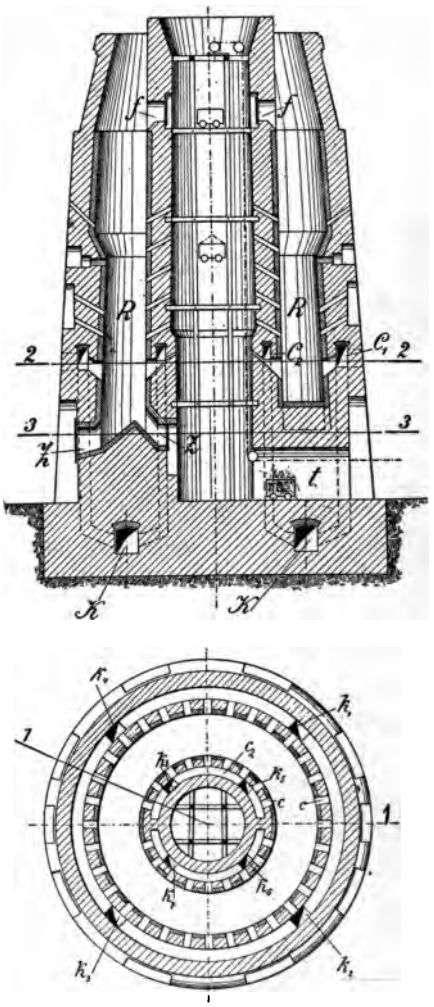


FIG. 149. VERTICAL SECTION AND PLAN OF SCHMATOLLA KILN.

Isserlis has designed a kiln of rectangular plan, which is shown in Fig. 148. The preheating shaft is separated by the separating walls *g* into compartments I, II, III, IV. Each one of these compartments is supposed to have a capacity of about 10 tons per day. The furnace shown in the illustration has four compartments, but this furnace can, of course, also be built with a larger

or smaller number of compartments. The producers and the discharging openings are arranged alternately at the longitudinal sides of the kiln.

A kiln which has been designed by Schmatolla is shown in Fig. 149. This kiln is said to have a high capacity and to be of low first cost, the excellent result being effected by the fact that a narrow shaft similar to a stack, open at both ends, is built into a very wide cylindrical or conical shaft. Hence, a ring-shaped shaft is obtained, which can be given any suitable width. In this kiln the producer gas is allowed to enter both from the inside and the outside wall, and the material can also be discharged through openings arranged in the inner or outer wall. An elevator can be run in the inner shaft for lifting the limestone to be charged into the kiln. The figure shows a vertical section through the center of the shaft, and also a horizontal section in line 2–2 through the zone of the gas admissions.

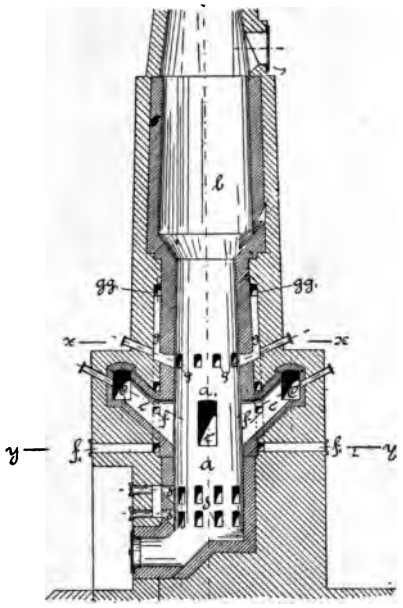


FIG. 150. ANOTHER TYPE OF SCHMATOLLA KILN.

The producer gas enters the ring channel K provided below the ring-shaped shaft and passes from here through vertical channels

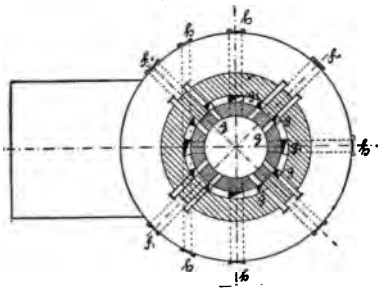


FIG. 151. HORIZONTAL SECTION ON x–x.

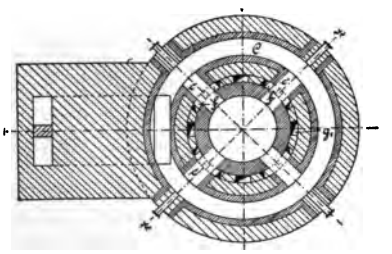


FIG. 152. HORIZONTAL SECTION ON y–y.

$k_1k_2k_3k_4$ to the outside ring-shaped gas channel C_1, and through four vertical channels $k_5k_6k_7k_8$ and to the inner ring-shaped gas channel C_2.

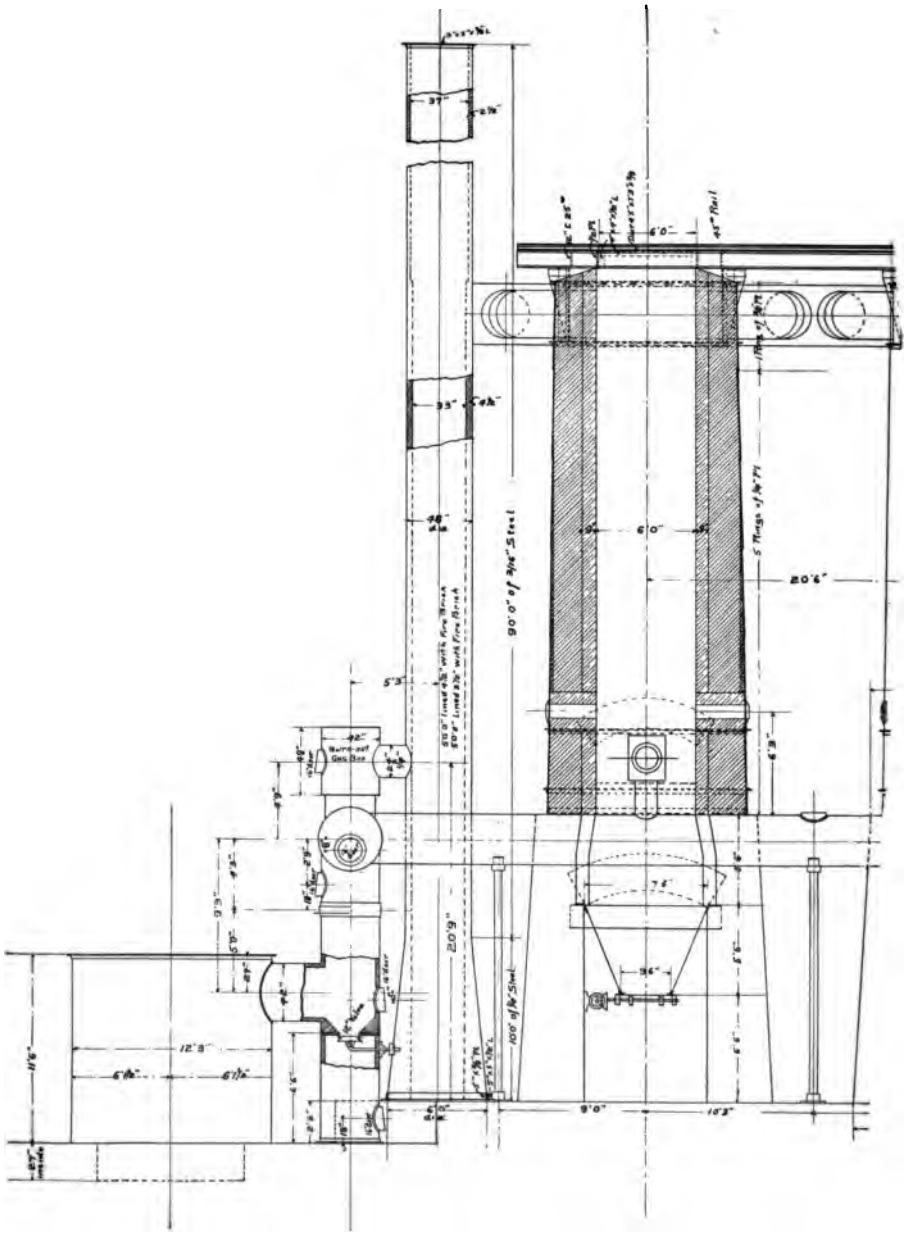


FIG. 153. PRODUCER GAS-FIRED LIME KILN.

A number of radially-arranged connected channels c lead to the ring shaft R, both from C_1 and from C_2. The combustion air enters

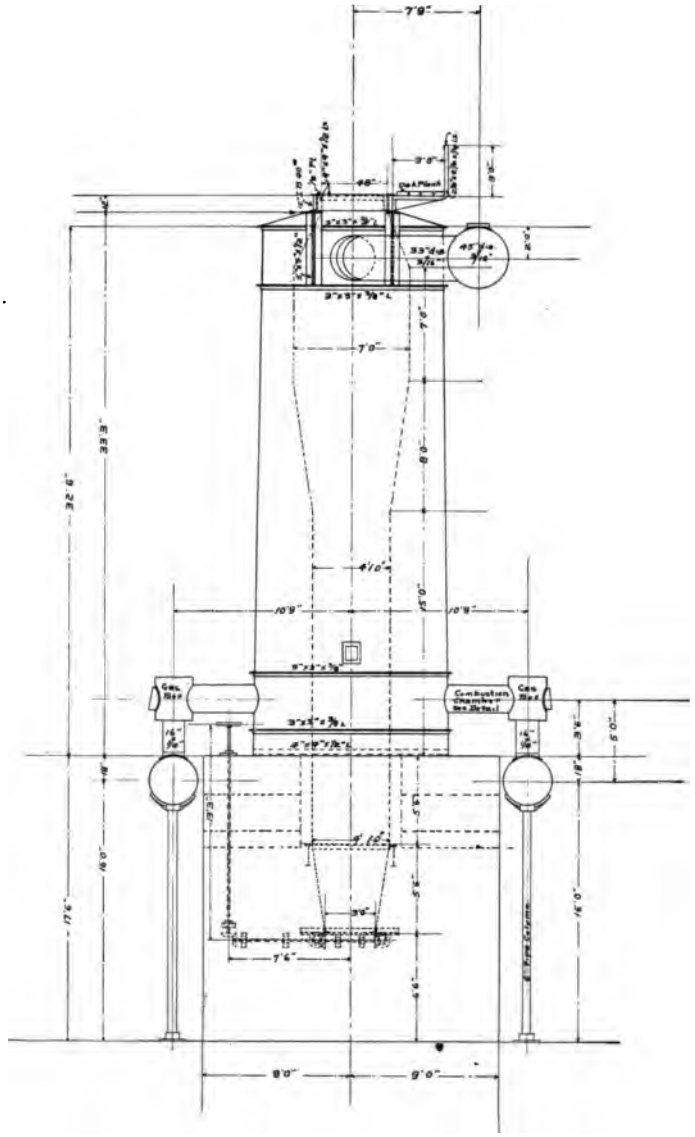


FIG. 154. PRODUCER GAS-FIRED LIME KILN.

through the outside discharging doors Z and the inner discharging doors z. The limestone is charged through openings f. The

central shaft is connected to the outside through tunnel-shaped channels *t*.

An excellent lime kiln designed by Schmatolla is shown in Figs. 150 to 152. Fig. 150 is a vertical section, 151 a horizontal section on line *x–x*, and 152 a horizontal section on line *y–y*. The gas enters the shaft from the main *C* through radially-arranged channels *c*,

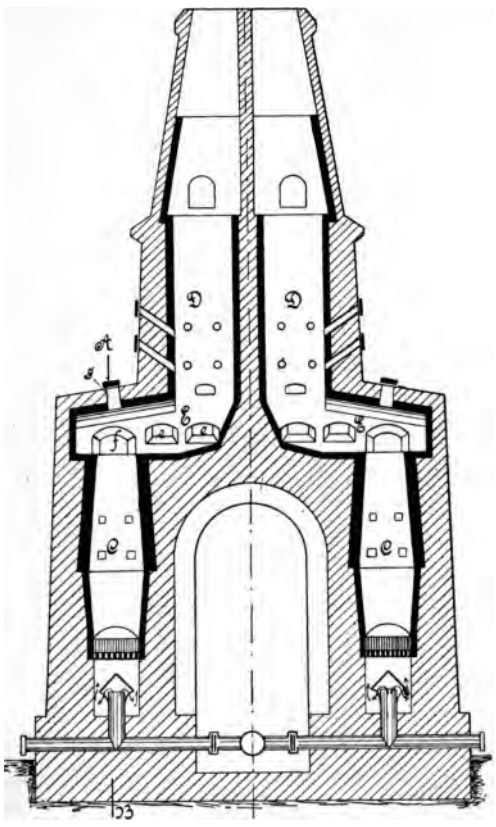


FIG. 155. VERTICAL SECTION OF DIETZ CEMENT KILN.

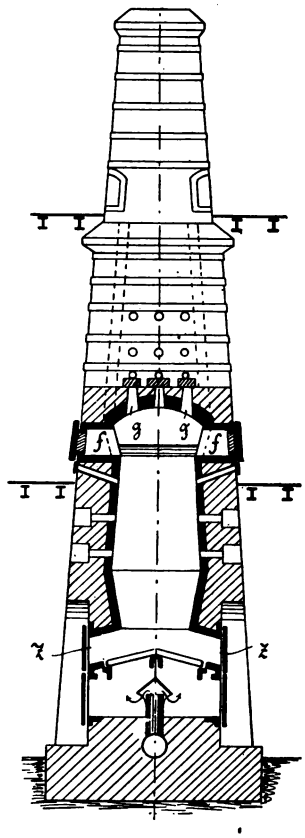


FIG. 156. TRANSVERSE SECTION OF DIETZ CEMENT KILN.

provided about six feet above the discharge openings. The secondary air enters through tuyeres *c*, directly above the discharge openings. The gas channels *c* are surrounded by a circular air channel, from which the air can enter into the gas channel through channels *f*, which are supplied from channels f_1. The secondary air entering through *g* passes through horizontal channels *h*, which are provided

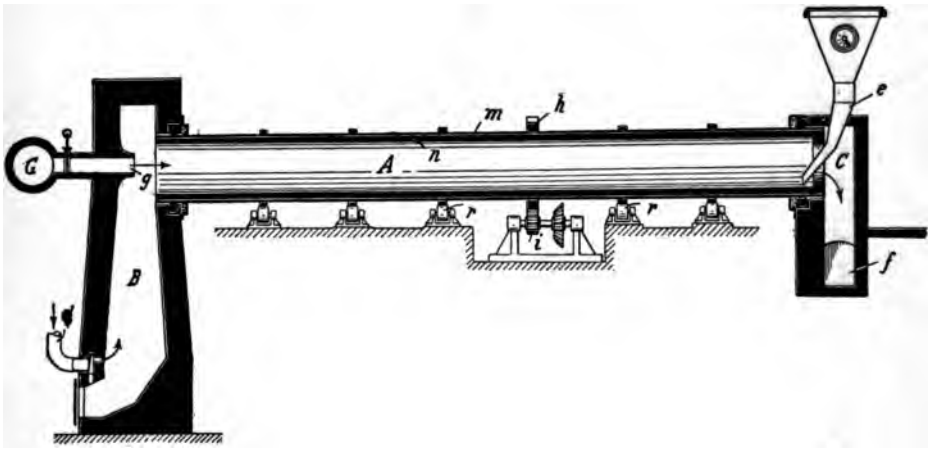


FIG. 157. GAS-FIRING ARRANGEMENT OF ROTARY CEMENT KILN.

in the cooling shaft and can be regulated by slides. At first the air rises through vertical channels g_1 arranged behind the fire-brick lining, and then goes downward through channels g_1. Both g and g_1 are of a T-shape. The secondary air passing through these channels, which are provided behind the incandescent brickwork of the shaft, is highly preheated. Figs. 153 and 154 also illustrate the installation and construction of producer gas-fired lime kilns.

A description of the Dietz cement kiln, which can be easily transformed to gas firing, will probably be of interest at this place. This kiln is shown in Fig. 155, a section on line AB in Fig. 156. The upper shafts are carried by the arch between the lower shafts. In

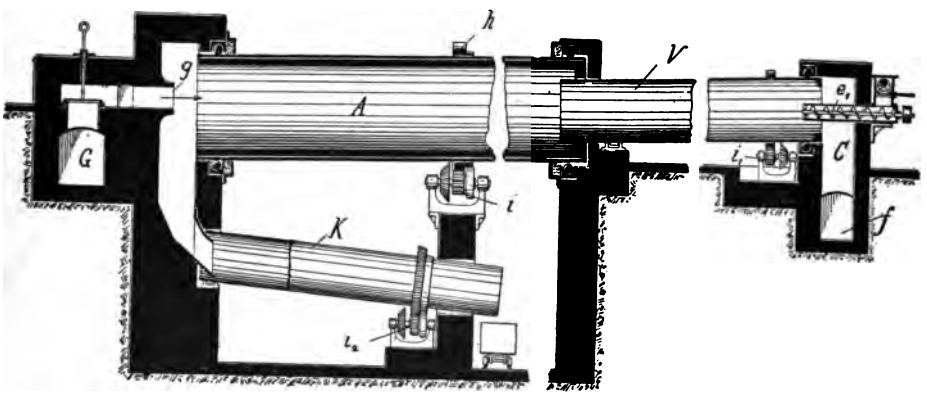


FIG. 158. ROTARY CEMENT KILN, WITH ARRANGEMENT FOR PREHEATING THE AIR.

the upper parts of the lower shafts *C* is the hottest zone, in their lower parts the cooling zone; the upper shafts *D* are the preheating shafts. They communicate through the hearth *E*, provided with working doors *e* and *f*. Fuel can be charged through openings *g* and distributed through doors *f*. Through doors *e* and *f* the material is raked from preheating shaft into the burning shaft proper.

From time to time the material is discharged through doors *zz;* fuel is charged through *g*, and then the preheated material drawn from the preheating into the burning shaft, while fresh material is charged from the top. For gas firing, arrangements have to be made for preheating the air.

If gas firing is used in rotary cement-kilns, the pulverizing of coal is done away with, a saving of about 25 per cent. effected, and a product free of ash obtained. Fig. 157 shows a longitudinal section of such a kiln. The material is charged through *C*, the gas enters through pipes *g* branching off the main *G*, while the air is entering through *d*, being highly preheated by passing through the burned clinker contained in *B*, the clinker being cooled simultaneously. There is no difficulty in producing the temperature required for cement burning.

In the kiln shown in Fig 158 the burned clinker is discharged through *K*, in which also the combustion air is preheated. The construction will be easily understood from the illustration.

CHAPTER VIII.

PRODUCER GAS-FIRED FURNACES IN THE GLASS INDUSTRY.

A typical furnace is shown in Fig. 159 (section *GH*), Fig. 160 (section *DE*) and Fig. 161 (section *GBF*). *d'd'* are the air, *d''d''* the gas regenerators, *bb* the flues strengthened by small piers *cc*,

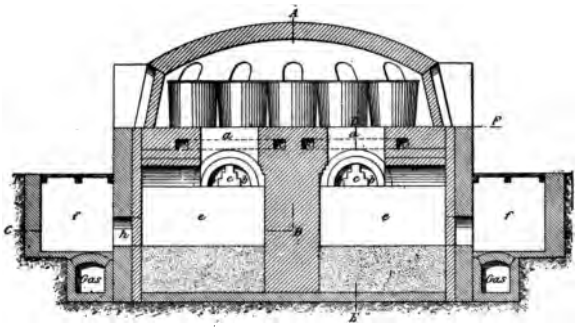


FIG. 159.

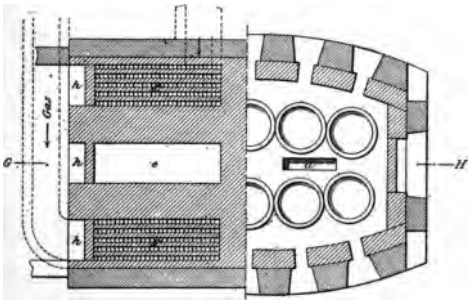


FIG. 160.

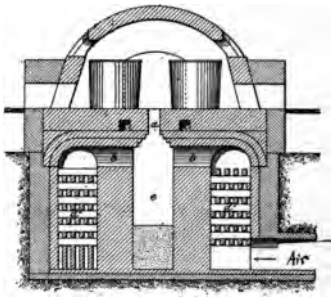


FIG. 161.

GLASS FURNACE.

ee the pockets for the hearth glass, *ff* the pits through which the pockets can be reached, *kk* cooling channels.

A Siemens regenerative plate glass furnace is shown in Fig. 162 (section *FG*), Fig. 163 (section *GDE*) and Fig. 164 (section *AB*). *aa* are the horizontal flues, *c'c''* the valves, *bb* the working holes, which are closed after the work is finished, in order to allow spontaneous combustion of the gas in the next batch.

A Siemens plate glass furnace is shown in Fig. 165 (horizontal section) and Fig. 166 (section *AB*). This furnace was first designed

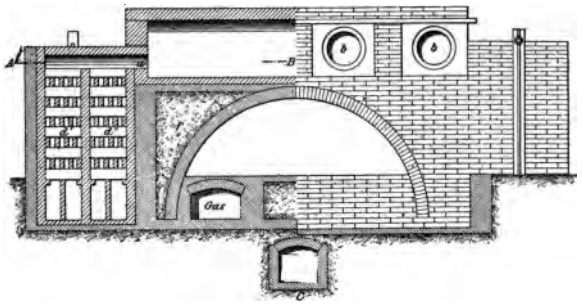


FIG. 162.

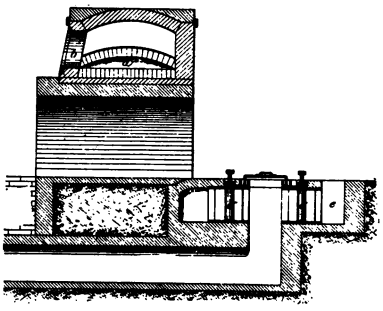


FIG. 163.

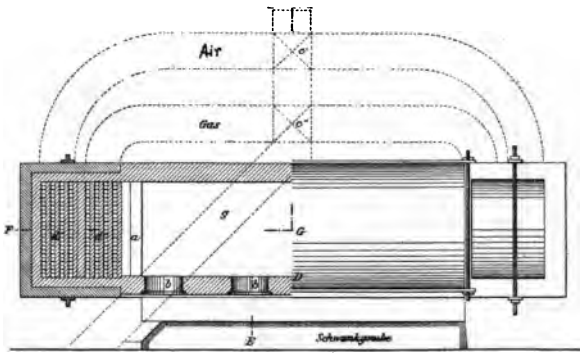


FIG. 164.
PLATE GLASS FURNACE.

for direct fire and only later transformed to gas firing. The branch channels *lmn* combine to the main sewer *h* of the producer. *m* furnishes the gas for spreading through slit *aa*, consumes the most

gas and is therefore, at *f*, provided with an air slit (10″ × 1″). *n* takes care of the preheating, *l* of the cooling fire by sending gas through flues *cc* and *b*–*b*′ respectively, *ss* are the stretching, *kk* the cooling cars, which are discharged and then returned through *vv*. The rolls are charged at *u* and the plates are transported to the respective cooling car (by means of a long fork) through opening *t*. Each of the three channels *l*, *m*, *n* is provided with a throttle valve.

A regenerative furnace for white and colored glasses of fine grade is shown in Fig. 167 (section *GH*), Fig. 168 (section *ABG*

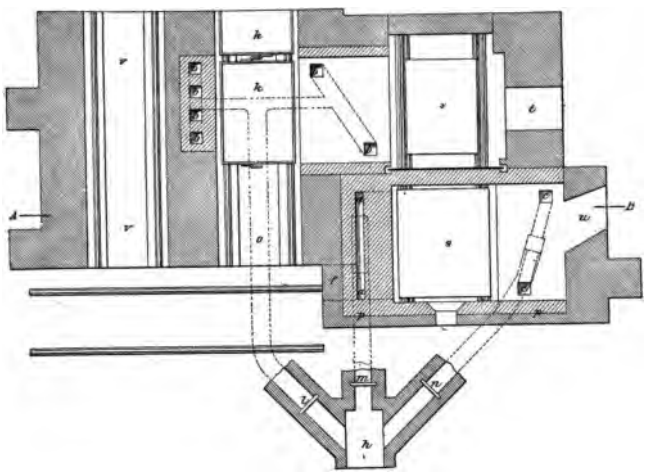


FIG. 165.

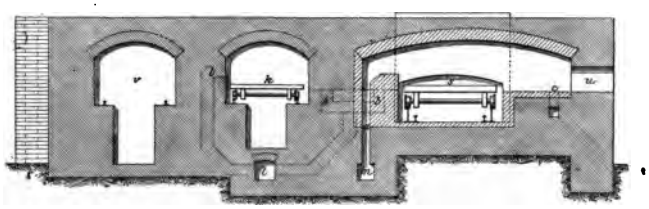


FIG. 166.
PLATE GLASS FURNACE.

and *AF*) and Fig. 169 (section *ADE*). The upper part is so arranged that manufacturing can be carried on simultaneously at all the eight pots. The lower part is about the same as in the plate glass furnace. *d*″ is the gas, *d*′ the air regenerator, *bb* the air and gas channels, *aa* the flues, *kk* the cooling channels for the latter and *ee* pockets for the hearth glass.

An English flint glass furnace with regenerative gas firing is illustrated in Fig. 170 (section *IK* and *EGH*) and Fig. 171 (section

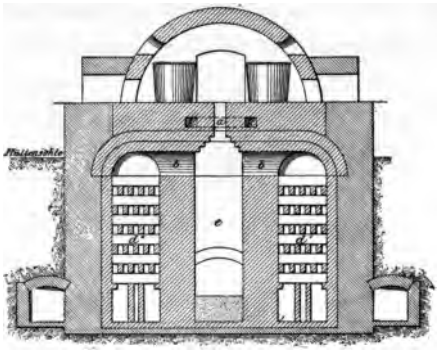


FIG. 167.

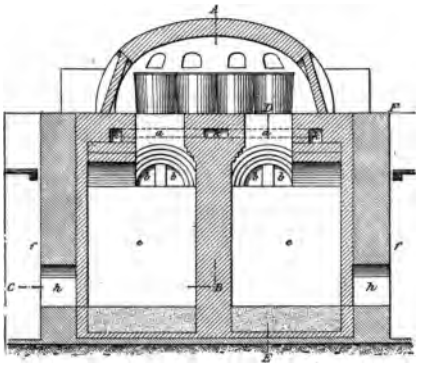


FIG. 168.

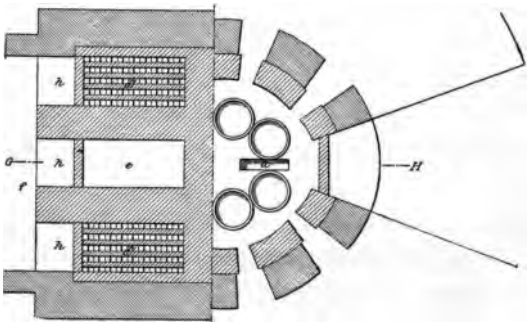


FIG. 169.
REGENERATIVE FURNACE FOR WHITE GLASS.

AB and *GDE*). The upper part is circular whereby space is saved, while at the same time the pots are easily exchangeable.

The purity of the gas flame allows the melting of this most sensitive grade of glass with open pots. *d'* is the air, *d''* the gas regenerator; the former has two, the latter three slits in the arch through which the gases go to channels *b''* and *b'* and from here to flues *aa*

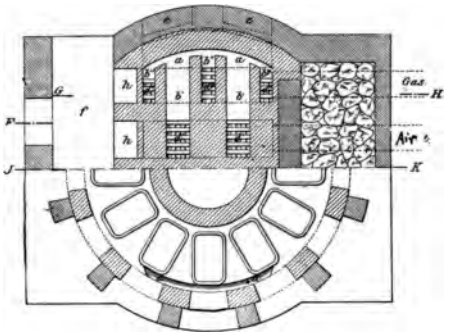


FIG. 170.

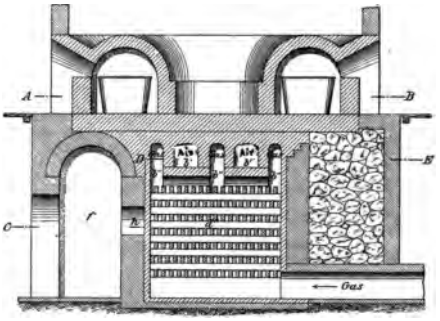


FIG. 171.
FLINT GLASS FURNACE.

where they combine. The hearth glass is removed through two openings *ee*. About eighteen hours are required for melting.

It is an old rule of the glass manufacturing practice to melt as much glass as possible in the smallest possible space, as hereby the losses by radiation are reduced and the melting process shortened. The result of these efforts is the combination of all the pots into one tank, which is used permanently for melting the same quality of glass.

These tank furnaces were only successful when Siemens succeeded to separate the melting process from the refining process. This appliance is shown (Figs. 172–177) in two constructions with installation in the melting furnaces. They consist mainly of three

communicating compartments open at the bottom. The compartment *B* receives the glass from the tank through openings *c*. Then the glass travels over partition *l* and openings *b* to the "working part" *A*. After being so purified it is here heated again and thereby refined. As the refining process progresses, the specific gravity of the glass increases and hence the latter sinks to the

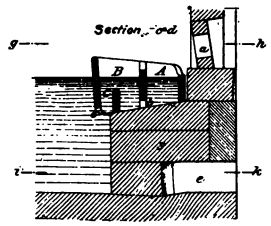


FIG. 172.

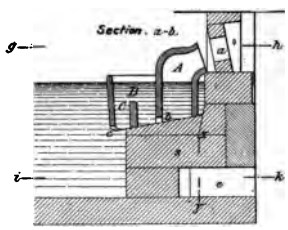


FIG. 173.

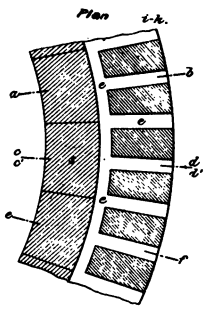


FIG. 174.

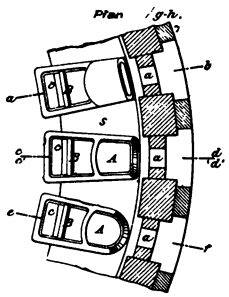


FIG. 175.

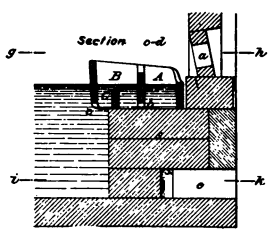


FIG. 176.

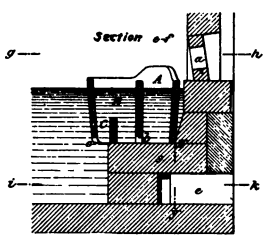


FIG. 177.

REFINING APPARATUS.

bottom, making room for the entering unrefined glass, whereby the refined glass is forced through *b* to *A*.

For certain grades of glasses it is necessary to protect the glass contained in *A* against a strong reheating. Figs. 176 and 177 are suitable constructions for such cases.

A Siemens monster furnace having a capacity of 25,000 bottles per day at a consumption of 15–18 tons of Bohemian lignite per day is shown in Figs. 178–181. The circular shape allows an excellent utilization of space and heat.

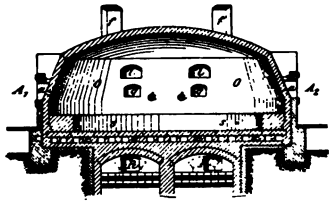


FIG. 178.

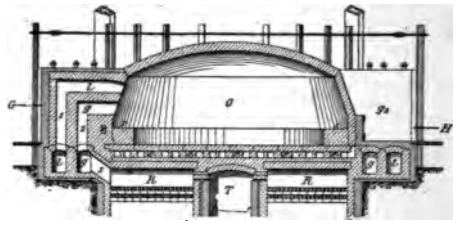


FIG. 179.

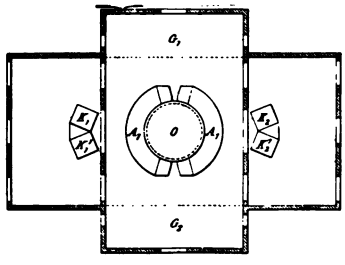


FIG. 180.

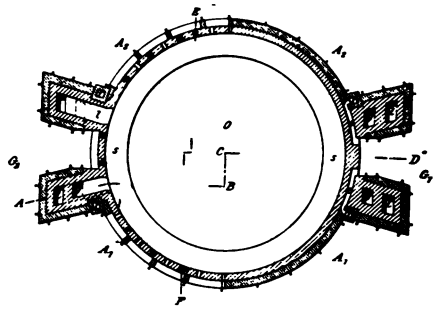


FIG. 181.

SIEMENS TANK FURNACE.

g and *l* are gas and air flues respectively, *ff* are small chimneys for the cooling channels. *kk* are the charging openings. Otherwise there are no special features in this furnace.

CHAPTER IX.

PRODUCER GAS-FIRED FURNACES IN THE BRICK AND CERAMIC INDUSTRIES.

Producer Gas-fired Brick Kiln.—Producer gas firing can be conveniently used in brick kilns and generally a direct-fired kiln can be transformed to gas firing at moderate cost.

The main advantage of the gas fire for this purpose is the fact that the heat of the burnt material can be utilized for preheating the combustion air. Furthermore low-grade fuel can be used, even if high temperatures have to be obtained or high-grade goods are to be burned.

With gas firing the material to be burned does not come in contact with ash, flue dust, etc.; thence fine goods which previously had to be burned in muffle furnaces can be burnt directly with gas. While with direct firing a number of fireplaces have to be operated, a saving in labor is effected with gas firing by the fact that only one producer plant has to be taken care of.

With gas firing an excess of air in the kiln or the admission of cold air is easily avoided.

It is evident that with only slight changes a coal-fired kiln can be adapted for gas firing. In place of the heating shafts (flues), vertical pipes (burners) closed on top, which are provided with rows of numerous gas-outlet openings or slits, have to be installed. These burners are connected by connecting flues or channels ar-

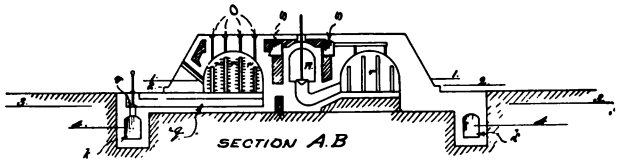


FIG. 182. PRODUCER GAS-FIRED BRICK KILN, VERTICAL SECTION.

ranged in the sole of the kiln and by a main gas flue going all around the kiln, as shown in Fig. 182 (vertical section) and Fig. 182*a* (plan). The gas is fed from a gas producer to the flue *K*.

Below every firing hole there are built in vertically fire-brick

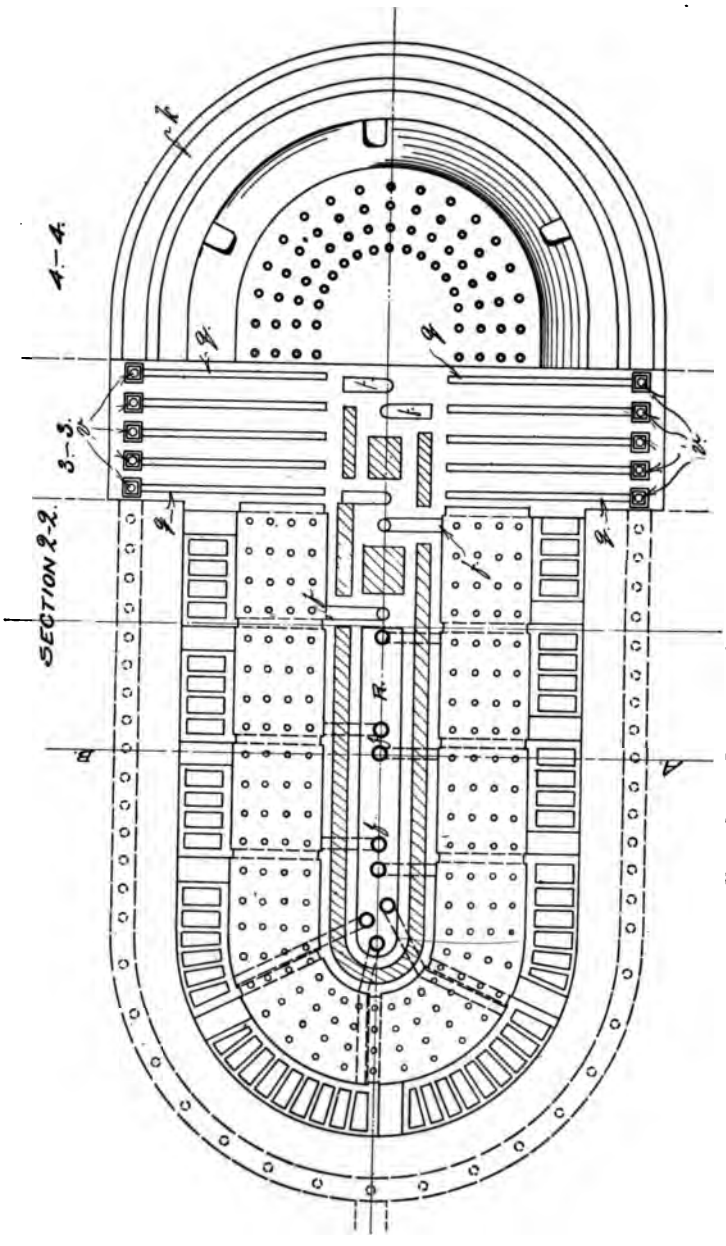


FIG. 182a. PRODUCER GAS-FIRED BRICK KILN, PLAN.

tubes R closed on top, which end with their open bottoms into the cross-flues. By opening valve v these flues can be connected with the main flue K, so that whenever the valve is opened the gas will

go to the connecting flue *L* and from here through the burner *R* into the burning kiln proper. The products of combustion are led through the flues *f* into the common flue *R*.

Through the flue *S* on top of the kiln hot air from a burnt-out chamber is conducted to a chamber charged with green goods.

As is seen from the above description, the air only is preheated in this case, while the gas goes to the kiln without preheating. This necessitates the use of a fairly good grade of coal, while by preheating the gas also low grade of coal and even lignite, peat or wood can be used without difficulty for burning the most refractory materials. In Europe the system of regeneration (preheating gas and air in chambers filled with fire-brick checker work, which are heated by the product of combustion) is widely used and in one fire-brick factory a saving in fuel of 40 per cent. and in time of 50 per cent. has been effected.

For the burning of goods which shall not come in contact with the fire gases, especially for burning fine enamels, muffle furnaces are used. In the heating of the latter, producer gas presents many advantages as compared to direct firing. The waste heat of the products of combustion is lost with coal firing, while with gas firing it is used for preheating the combustion air. With gas firing the heat radiated by the furnace can be considerably reduced by arranging air slits behind the fire-brick lining and leading the combustion air through same for the purpose of preheating.

Buehrer's Gas-fired Kiln for the Ceramic Industries.—This furnace, which is shown in Figs. 183, 184 and 185 consists of a number of burning channels *OO*, communicating with each other through the connecting points *CC*, so that a construction similar to a ring-kiln is obtained.

The kiln is charged and discharged through doors *pp*, *GG* are the producers. Behind the latter are the gas-collecting spaces *SS*, from which the gas passes through valves *X* and the mains *gg* to the

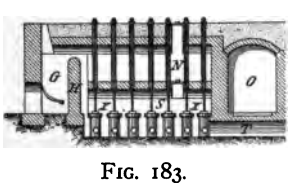


FIG. 183.

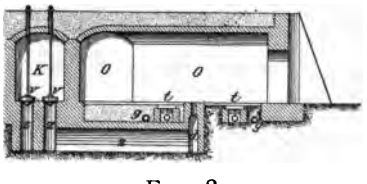


FIG. 184.

BUEHRER KILN.

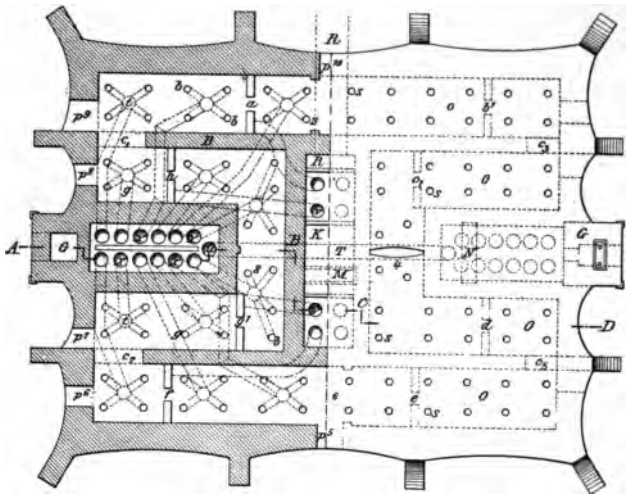


FIG. 185. BUEHRER KILN.

small gas collectors *t* and from these through burners *bb* to the places of consumption in the kiln. The two spaces *SS* are in communication through channel *T* and its valves *uu* respectively.

The products of combustion travel through the slits *a, b'c'd–h* to the smoke channels *Z* provided with valves *v,* then through the smoke-collecting flue *k* and main flue *R* to the stack. *SS* and *K* are accessible through shafts *N* and *M*.

In starting a new furnace a number of small fires is started at various points of the furnace, then all openings are closed, except p^3 and p^4 through which the fuel is charged.

Now the fire is increased, also in the two producers, and the smoke valves *v* leading to slits *a, b', c'd* and *e, f, g, h,* respectively, are opened and finally the gas valves *X* in the vicinity of the open flues, whereby a drying of the entire furnace is effected.

Now the doors are opened, the burners in the two first compartments covered, a temporary grate put in near the door of compartment p^9, and above the grate a temporary wall erected in order to close the furnace channel. Then the charging is started behind the wall.

In charging, a small space is left free around the burners and below the poke holes. When two compartments are filled, they are separated from the rest of the kiln by a slide, then fire is started

upon the grate and valve *v*, which is in connection with flue *a*, opened, in order to produce sufficient drafts.

The fire is gradually increased, and, as soon as the bottom through the first poke-holes appears bright, fuel is charged also through these poke-holes, *a* is closed and *b'* opened.

Charging is continued and, when poking can be done through six to eight holes, the slide is transferred from three to four, *b'* closed and *c'* opened.

Now the producers are put to action, after allowing the first "wild" gas to escape through the stack.

When the bricks at the front flames are so hot that they appear bright to the bottom of the furnaces through two further series of peep-holes, the four corresponding burners *b* are started. If, finally, the fire is in sixteen or twenty holes, the burning operation enters the normal stage, and for every burner put in operation in the front, a burner in the back is stopped. At the same time material is charged and discharged.

The Mendheim Kiln.—The gas travels (Fig. 186, 187) from the producers *aa* through the main *b*, d^1, d^2 provided with valves c^1c^2. A valve *e* is provided for each chamber.

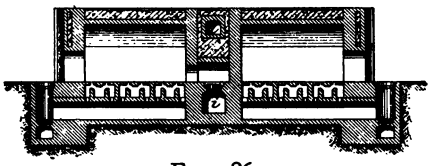


FIG. 186.

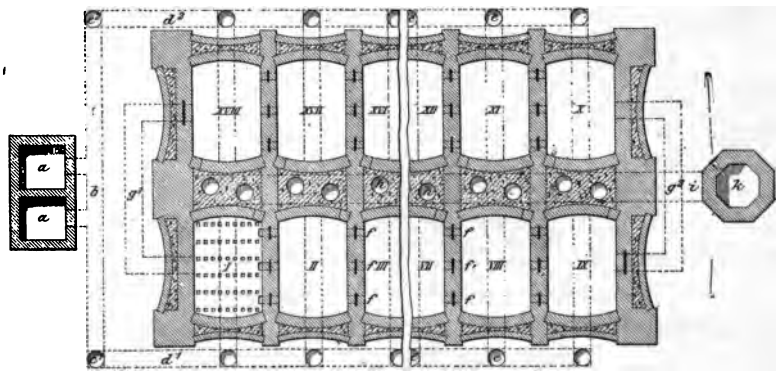


FIG. 187.
MENDHEIM KILN.

The operation is as follows: We assume that chamber *VIII* is to be put under fire. The current of air has passed already through the ready burnt, cooling chambers *XVII, XVIII, I, II* and so on to

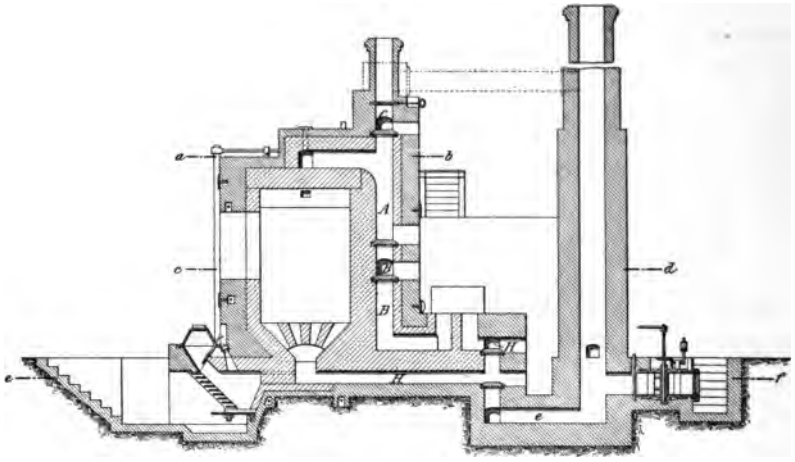


FIG. 188. EHRENWERTH KILN. Section *AB*.

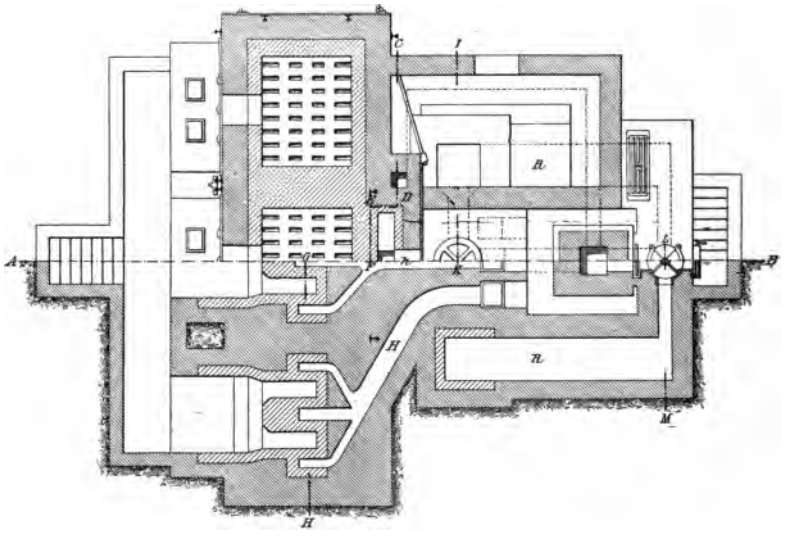


FIG. 189. EHRENWERTH KILN. Section *cd* and *ef*.

VII, and through channel g' (slits *ff*) between chambers *XVIII* to *I*, being thereby sufficiently hot for igniting the gas. The flame goes from *VIII* through *ff* to *IX*, then through channel g^2 to X and

so on, gradually, to *XVI*. The latter chamber is separated from *XV* by a slide and is connected with flue *i* and stack *k* by opening valve *h*. If the burning of the charge in *VIII* is finished, gas valve *e* is closed, and the one leading to *IX* opened, this operation being again and again repeated, just as in a ring kiln.

Ehrenwerth's Regenerative Kiln for Ceramic Industries.—This furnace is shown in Figs. 188 to 191. The producer shown in the cut is a step grate producer, which can also be used as direct fireplace by keeping the fuel bed correspondingly low. The combustion air is heated in regenerators *RR* and enters, in the cuts shown, the burning chamber at the opposite end. The rising flame current

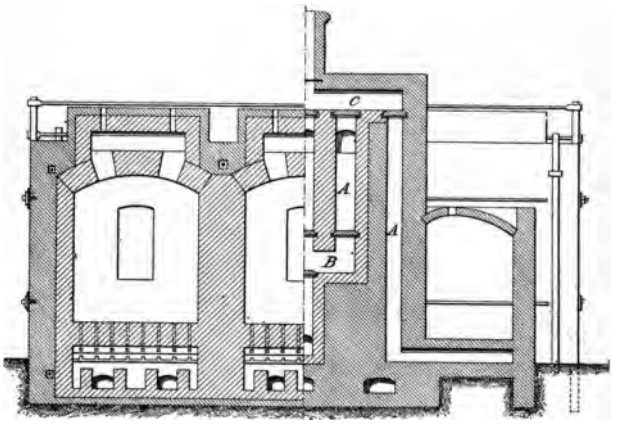


FIG. 190. EHRENWERTH KILN. Section *CDEFGH*.

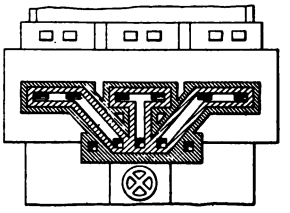


FIG. 191. EHRENWERTH KILN. Section *ab*.

is here divided. One *part* of the flame goes downward into one of the regenerators, the second *part* is used continuously for heating the air, while the second flame current is led either directly to the stack or to the drying chambers. The current is periodically reversed. The various currents of the products of combustion are regulated by slides suitably arranged in *A*, *B* and *H*. The flame of

the preliminary fire is led directly to the stack, until it is certain that sufficient heat for the regenerator is at disposal. Now the producers are put into action. It is evident that this furnace must have a certain number of burning chambers—probably two times

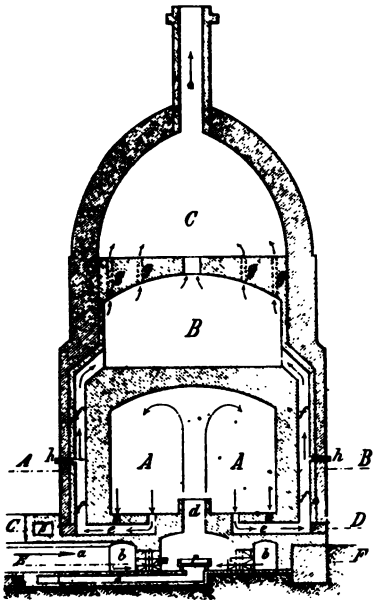


FIG. 192.

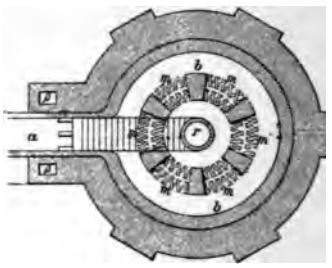


FIG. 193.

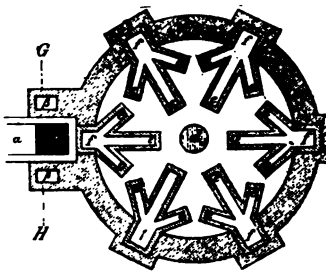


FIG. 194.

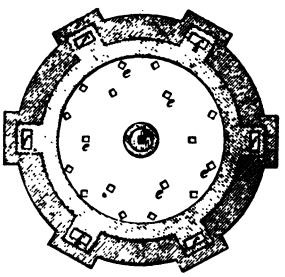


FIG. 195.

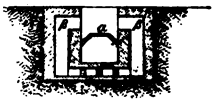


FIG. 196.

VENIER'S FURNACE.

four—all of them connected to the regenerators. All branch channels must end in one common flue; along these lines this construction may be changed from an intermittent to a continuous one. The use of part of the waste heat in the drying chambers means a

unnecessary complication and possibly also the danger of insufficient chimney draft.

Venier's Furnace for Burning Porcelain.—Fig. 192 shows the vertical section of the kiln; Fig. 193 the lower part (plan) on line *EF*; Fig. 194 the horizontal section on line *CD*; Fig. 195 plan on line *AB*; Fig. 196 the vertical section of the gas and air channels.

The gas enters through *a*, the gas and air are mixed and ignited at the cast-iron grate (Figs. 194 and 196) and the flame goes through the lower part of the furnace (Fig. 193) to *c*. Here it meets that heated air, which, entering cold through the two side openings *ββ*, goes downward below the gas channel *a*, is heated in

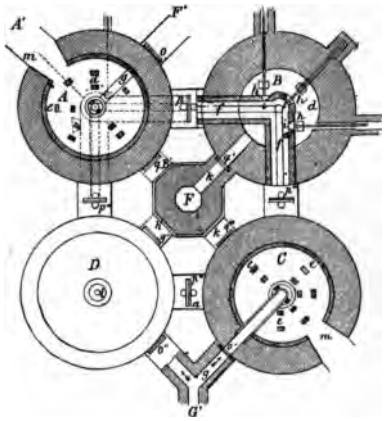


FIG. 197.

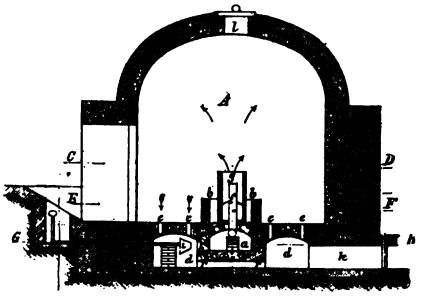


FIG. 198.

STEINMANN KILN.

air channel δ and finally hits the plate *r* (Figs. 192 and 193) whereby it is distributed in all directions and thoroughly mixed with the gas.

The fire goes through *d* to *A*, and is then led downward through openings *ee* (Fig. 195) and channels *ff* to the second story *B*; from *B* it goes through flues *gg* to the top chamber *C* and then to the stack.

The draft and temperature of *A* are regulated by slides *hh* provided in channels *ff*.

Steinmann's Continuous Four Compartment Gas Kiln for Bricks, etc.—This kiln is shown in various sectional and also the top view in Fig. 197. Fig. 198 shows a vertical section through a chamber (*A*) on line *A'B'*.

The kiln consists of four chambers *ABCD*, the stack *F* and the two producers located near *F'* and *G'*. The one at *F'* communicates with chambers *A* and *B*, the one at *G'* with chambers *C* and *D*.

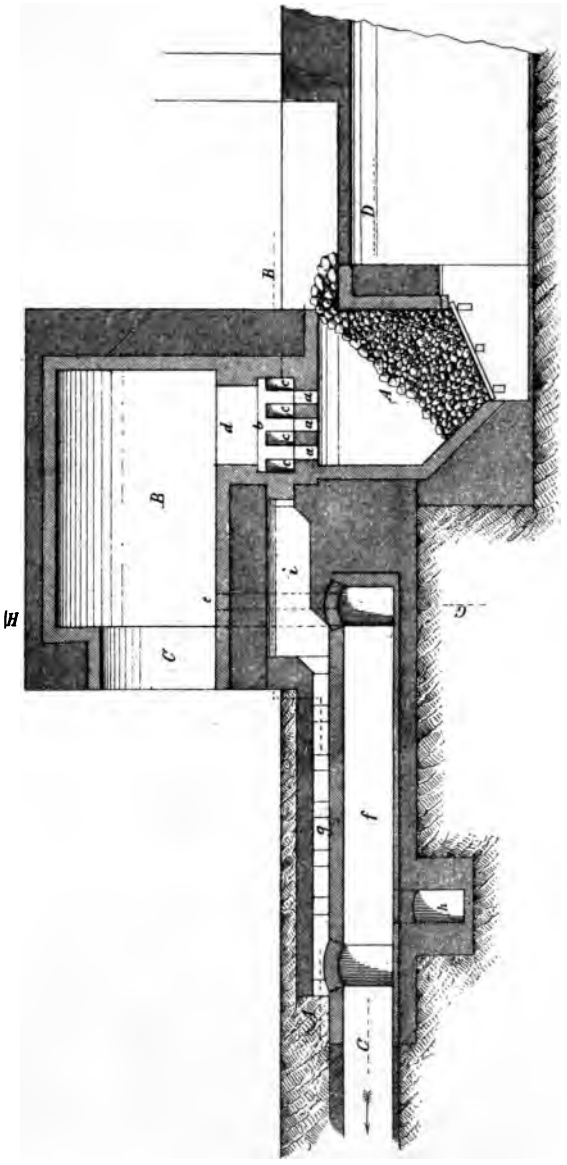


FIG. 199. NEHSE KILN.

gg are the gas channels; *ff* the pipes for the combustion air; *dd* the smoke channels with inlets *ee*; *aa* the common connecting chan-

nel for all four "burning" chambers; *cc* the outlet of this channel into the "burning" chambers; *hh* the connections to the main *aa*; *ii* the closing devices for *hh*; *kk* the flues to the stack; *l* the "cooling door" and *m* the charging entrance.

When charging *A* is filled with goods, *m* closed by means of brick work and then the preheating started with a preliminary grate which is removed as soon as the interior of the chamber appears dark red:

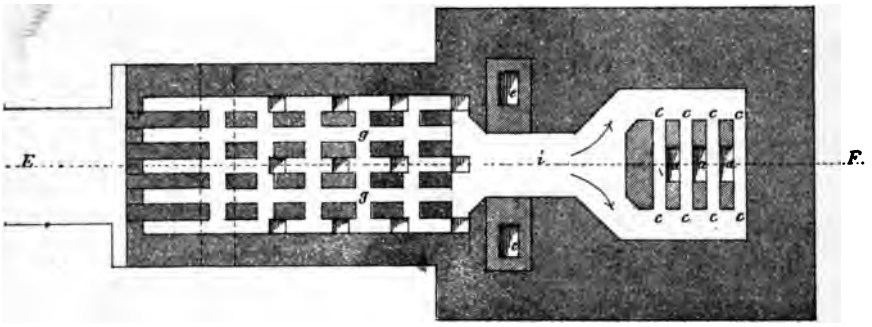


FIG. 200.

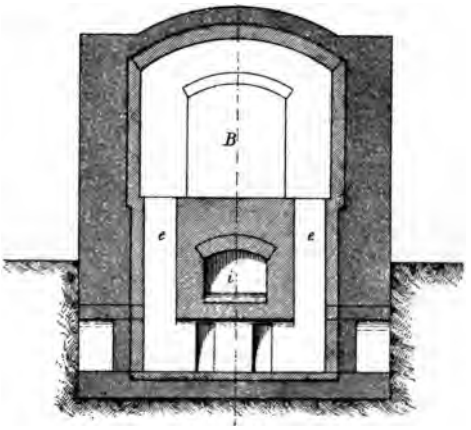


FIG. 201.
NEHSE KILN.

Now the gas valve *o* and the corresponding air line are opened, so that the gas flame is gradually developed passing through *ee*, partly also through *bb* and *hh* to channel *aa* and from here through slits *cc* into chamber *B*. From *B* the products of combustion pass through *ee*, *dd* and *k* to the stack.

The intensity of the flame increases with the increasing tempera-

ture of the air pipe *f*. Through outlets *rr* the main *a* communicates with flue *dd*.

When the burning process in *A* is finished, the chamber *B* and its air pipe are sufficiently hot, so that the gas can be allowed to enter.

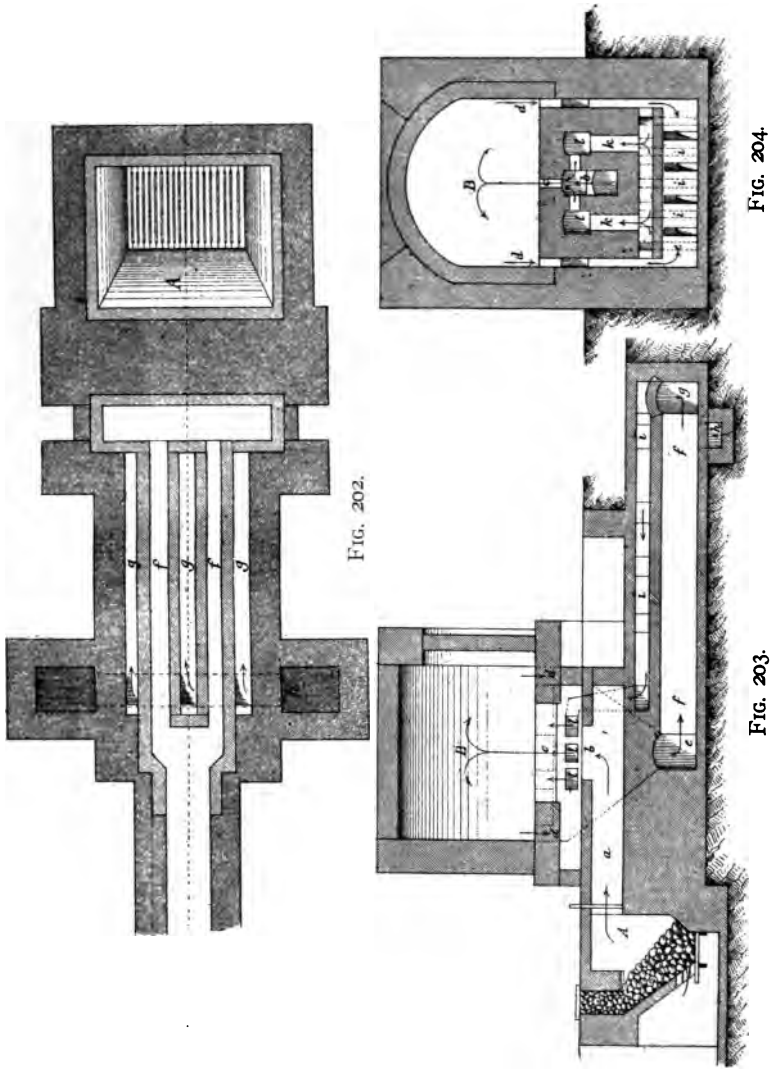


FIG. 202. FIG. 203. FIG. 204. NEHSE KILN.

Valves *o*, *p* and *q'* are closed, *o'*, *p''* and *q''* opened. *iii* in *B* are closed, *iii* in *C* opened, after this chamber has been charged. The flame travels now through *B* and *C* in the same manner as formerly

through *A* and *B*. Meanwhile *A* is discharged and *D* charged. For the operation from *C* to *D*, and from *D* to *A* the other producer is used.

Nehse's Gas Kilns for Burning Silica Bricks, etc.—Fig. 199 shows this furnace in longitudinal section, Fig. 200 in cross section, Figs. 201 and 202 in plan. It is of advantage to have the producer right at the furnace, as shown, as in this case it can also be used as direct fireplace—by keeping the fuel bed low, for preheating the furnace. From producer *A* the gas goes to *b*, meets the combustion air entering through *cc* and travels, as flame, through slits *d* into the furnace *B*. The production of gas is regulated by slides provided in openings *aa*, the quantity of air by a slide in channel *h*.

The charging operation *C* is closed with fire-bricks before starting a burning operation.

The flame reaches the furnace proper through *d*, rises to the arch and leaves through openings *ee*, passing through the air-heating channels *ff* to the stack. The air enters at *h* and travels through *gg* (counter-current principle).

A modification of this kiln is shown in Figs. 203 and 204. The gas travels from *A* through *a*, *b* and *c* to *B*. The products of combustion go through openings *d* to channel *e* and from here through channels *f* to the flue *g* leading to the stack.

The combustion air enters through openings at *h*, circulates between channels *f*, being preheated on its way, passes through channels *k* and openings *ll* and meets the gas below opening *c*, so that always a perfectly developed flame will reach the furnace proper.

The quantity of air is regulated at *h*, the quantity of gas at *a*; depending upon the regulation an oxidizing or reducing flame is obtained.

CHAPTER X.

THE SELECTION OF REFRACTORIES.[1]

A Consideration of the Kind and Quality of Brick Best Suited for Various Parts of Different Furnaces.

The question of refractories is recognized by all iron and steel men to be of the utmost importance. Outside of raw material, fuel, labor and power it is probably the largest item entering into the cost of the product whether that product be pig iron from the blast furnace, refined iron, or steel in any form.

This chapter is intended to discuss, within its limits, and from the standpoint of the manufacturer of refractory materials, the different kinds of furnaces used in the manufacture and treatment of iron and steel.

"Refractory" is defined as "Resisting ordinary treatment; difficult of fusion, reduction or the like." In so far as the brick business is concerned, the word "refractories" relates to and includes all the materials that have been found useful for the manufacture of fire-brick, or for use in other forms where the ability to resist excessive heat is required. In addition to being required to withstand heat, refractory materials are frequently subjected to one or more of the following conditions: (1) Chemical action of powerful fluxes and slags, (2) reducing action of gases, (3) sudden heating and cooling with wide temperature variations, (4) pressure and grinding action, (5) abrasion, (6) cutting and impinging flame, (7) combination of one or more of above, with heat.

The refractories in general use are (1) fire clay (base kaolinite with a composition of $Al_2O_3 + 2SiO_2 + 2H_2O$), (2) silica (ganister rock), (3) magnesite, (4) chrome ore.

Bauxite, carborundum, siloxicon and other substances have been proposed and in a few cases are in limited use for certain special types of furnaces. Bauxite especially, is valuable as a refractory under certain conditions and will probably come into greater use in the future.

Blast Furnace.—The modern manufacturing unit for the re-

[1] From data compiled by the Harbison-Walker Refractories Co.

duction of iron ore consists of one blast furnace and four stoves with the necessary piping and power plant. When we consider that furnaces are burdened with ores of such different character as Clinton hematites of the southern states, hard ores of Lake Superior, Mesaba soft ores, high sulphur ores of the Cornwall ore beds in Pennsylvania, limonite and so called mountain ores of Virginia and Tennessee, some of which contain appreciable quantities of zinc, magnetites of eastern Pennsylvania, New Jersey and New York, and hematite ores from Cuba, etc., it is easy to understand that conditions must vary greatly. These variations are intensified by further differences in the quality of fuels, design and operation of furnaces, grade of product and character of management.

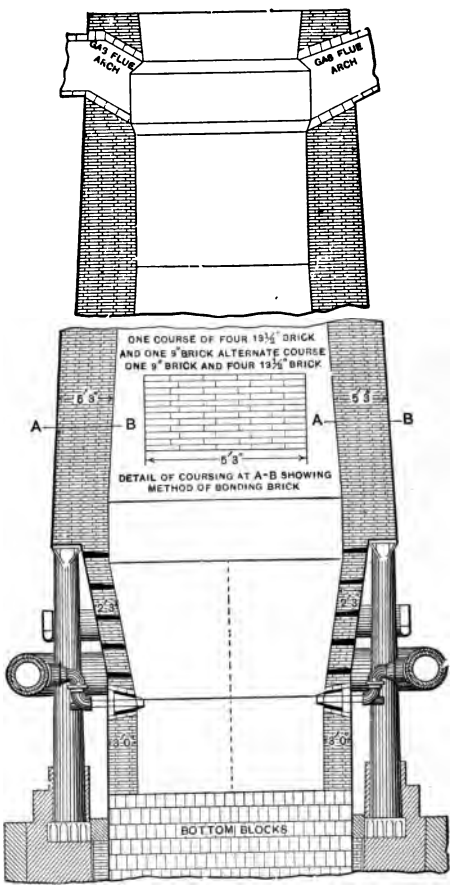


FIG. 205. SECTION OF BLAST FURNACE SHOWING CONSTRUCTION OF LINING.

A proper understanding of the conditions under which a furnace is operated being obtained, the selection of the brick becomes a matter of importance. All clays are not suitable for being made into brick for blast furnace linings. In some cases manufacturers of brick have a hard clay that could be used, but the bonding clay is not of the correct composition. Assuming a proper selection of raw clays, wide and varied experience in making blast furnace linings is necessary to a knowledge of how to mix and manipulate these clays so as to make brick which shall have the maximum resistance to the conditions in the furnace,

Among the chief causes which lead to wearing away the furnace linings, we may include:

1. The actual wear due to contact with the descending charge. This is relatively unimportant.

2. The action of alkalies, and of cyanides and other substances present in furnace gases. The effect of these is not yet accurately determined.[2]

3. The action of salt or other alkaline substances contained in the coke. By some authorities this is considered one of the most important causes of wear. At moderate temperatures salt is combined with silica and a fusible silicate is formed.

4. The flaking of bricks due to the deposition of carbon from carbon monoxide around iron particles reduced from impurities in the original brick.

5. The destructive action on the furnace wall caused by slips and scaffoldings tearing the brick-work away.

6. The channeling caused by the blast making its way up against the wall of the furnace instead of through the mass. This blast is charged with particles of coke, ore and limestone, and acts somewhat as sand blast in cutting out the brick.

7. Poor bricklaying and the use of inferior clay.

8. Too rapid heating of brick after re-lining. This steams the brick and injures the bond. Too rapid heating up sometimes causes the furnace walls to crack. If the furnace is forced before the carbonaceous coating has been deposited the lining is deprived of the indispensable protection of this coating and its destruction is sometimes only the question of a few months or weeks.

9. The actual wear due to the fall of ore, limestone and coke against the top walls of the furnace.

10. Irregular and faulty distribution. It is safe to say that this has been one of the prime evils that blast furnace managers have had to contend with for the past few years, due to the introduction of mechanical filling. Irregular or poor distribution is one of the most fruitful causes of failure of blast furnace linings.

[2] A noted authority attaches much importance to the action of cyanides, stating that the reduction of the residual oxide of iron in the lowest region of the blast furnace is accomplished chiefly through the agency of cyanides formed near the tuyeres. The alkaline salts condense in the upper part of the furnace and are brought down to the level of the tuyeres as the materials descend; thus, each particle of alkaline metal does duty over and over again, the alkalies introduced in small quantities in the fuel accumulating in the furnace.

11. Bringing the furnace up to capacity too soon after blowing in. Much prolonged discussion has taken place regarding the injurious effects of bringing up to capacity too quickly. The consensus of the best opinion is "If the furnace is brought up to full capacity in less than from six to eight weeks after the first iron is made, injury has probably been done to the lining."

12. Forcing the furnace. The pressure for output in recent years has unquestionably been responsible for some so-called failures of furnace linings. Pressure and volume of air have in some cases been pushed beyond all reasonable limits with consequent rapid deterioration of the lining and no corresponding advantage in tonnage or grade of output.

13. The destruction of the bond by the reducing action of carbonic oxide and other furnace gases at high temperature and pressure on the bonding impurities in the brick, whereby their physical structure is weakened and they are rendered friable. When the brick reach this state they are quickly worn away.

Selection of the Brick.—Several of the causes which contribute to the rapid destruction of blast furnace linings can be prevented to a considerable extent by the proper selection of the brick used in the lining. The varying conditions in blast furnace practice, with which the fire-brick used in lining the furnace are so intimately connected, that it is apparent that to make brick best suited for these varying needs, demand intimate knowledge and careful study on the part of the manufacturer who aims to make blast furnace brick best suited to each particular case.

As a concrete case it is sufficient to refer to the fact that merchant furnaces varying their product to meet the market, are much harder on linings than furnaces running on the same grade of iron year in and year out.

It is important to remember that uniformity is a most important quality of brick used in blast furnace linings. All the brick used in the hearth and bosh, inwall and top, should be of uniform mix, grind and burn for their respective places in the furnace.

The necessity of using a considerable proportion of calcined clay is evident to the brick manufacturer whose object it is to make a blast furnace lining of the highest quality. Brick made of all raw clay contain from 10 to 14 per cent. of combined water which is only driven out at a red heat in the kilns. The driving out of this water

causes shrinkage and develops internal stresses and distortion. The use of calcined clay diminishes the amount of combined water to be expelled with obvious advantages to the brick.

Hearth and Bosh Brick.—If hearth and bosh brick are burned at high kiln temperatures and are all burned in the same position in a large number of kilns it will insure their being better for the lining of blast furnaces than if they are burned and shipped "run of kiln." It is of course more expensive to burn brick at a high temperature than at a low temperature but the added expense adds qualities to the brick that are essential in blast furnace linings. It develops and utilizes to the highest extent the bonding qualities of the clay, brings out the small amount of iron present as an impurity and combines it with silica in the brick as a silicate of iron, and renders the brick tough dense and hard so that they resist disintegration by the reducing action of the blast furnace gases at high temperature and pressure. It is of course essential that brick for the hearth and bosh be of the highest possible refractoriness.

Inwall Brick.—The lining in the inwall is not protected much above the bosh line by cooling plates, except in some few cases where they have been run well up in the furnace. The wearing away of linings is most pronounced in the inwall above the bosh. Brick for the inwall should be exceedingly hard, dense and refractory. As compared with hearth and bosh brick they can be slightly less refractory. This insures an increase in their hardness and density, when burned hard.

Top Brick.—The top brick must be hard; harder than those for hearth, bosh and inwall. They must also be tough and of the greatest possible density.

Laying Brick.—After having procured a good lining it is necessary to put it in the furnace properly. This requires constant and uniform care on the part of some one in authority. Clay of the same grade as the brick should be used in laying them and not more than 300 to 350 pounds to 1,000 nine-inch equivalent brick. Tempering the fire clay with steam adds to its plasticity.

All brick intended for use in a blast furnace should be kept dry, and especially they should not be frozen. All fire clay brick absorb moisture and if they are subjected to freezing temperatures the bond is weakened or destroyed.

The upward expansion of the lining in a modern 80 or 85 foot furnace may be set down at from 3 to 4 inches.

Bottom blocks should be set up and trimmed if necessary to make knife edge joints. Rectangular bottom blocks 18 x 12 x 8 inches have largely taken the place of cone bottom blocks which were used for a great many years. The rectangular blocks are very dense, true, easily laid and require very little chipping or cutting.

Especial care should be taken that the brick in the crucible of the furnace around the tuyeres and cooler plates are carefully laid with very close joints. The proper proportion of shapes, such as arch, wedge, split, etc., should be used instead of cutting straight brick to make these shapes. Throughout the furnace the utmost care should be taken in laying brick with close joints.

In laying brick in the crucible of the furnace it is customary at some plants to use pine strips ¾ inch to 1 inch wide. These are placed between the brick work and shell about 18 inches apart. In some cases brick are laid up practically tight to the shell and slushed in with fire clay. The use of pine strips is probably the better practice.

Piping Brick.—The matter of brick for piping is a most important one and in recent years the most progressive manufacturers have made brick of a special mixture for lining the various connections of the furnace and stoves. Many furnaces have had disappointing results from using for piping brick that were not suited for the purpose. These were either bought because they were cheap, or for the reason that the furnace manager did not pay so much attention to the brick for piping as to the brick for furnace linings.

Brick manufacturers have had the matter of piping brick brought to their attention very forcibly in recent years and the necessity of understanding the conditions prevailing in the piping of the furnace and of meeting these conditions by proper variations of the mix, grind and burn of their clays, is known thoroughly, by the most progressive among them. It is necessary to remember that conditions in the hot and cold sides of the stove are different and brick should be varied accordingly.

The ease also with which repairs are made to brick work around hot blast valves, etc., compared with brick repairs in blast furnace and stoves proper, has no doubt prevented blast furnace managers from giving as much attention to brick for this purpose as seems desirable. There is no doubt but that unnecessary expense has been

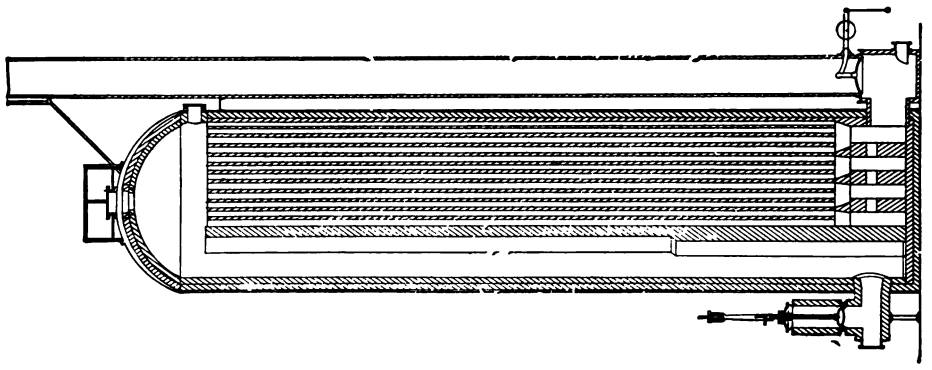


FIG. 208.

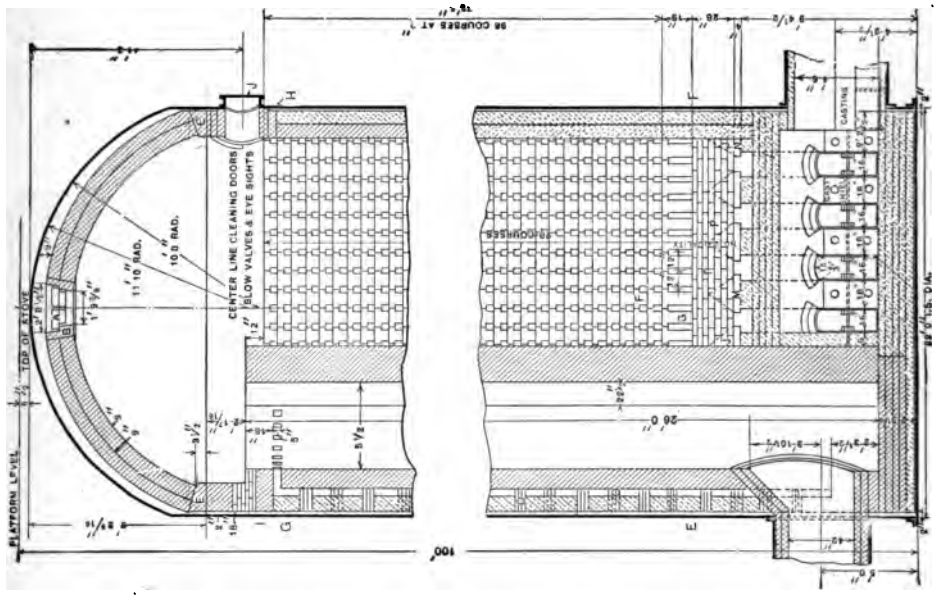


FIG. 207.

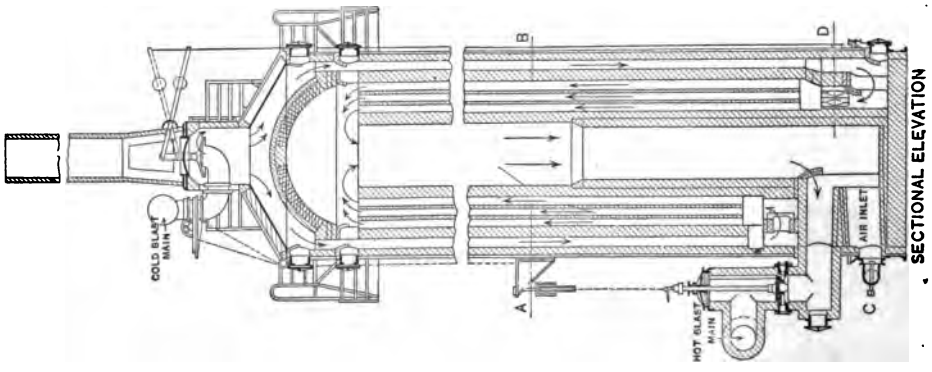


FIG. 206. SECTIONAL ELEVATION

incurred through the use of unsuitable brick, which could have been saved by a knowledge and recognition of the fact that brick of quality entirely suitable for these places are now being made by some manufacturers who have at all times made it part of their policy to keep informed on the conditions prevailing in the different parts of the furnaces to which they supply brick.

Cooler Arches.—Over 90 per cent. of the furnaces in the United States use standard shapes over the cooler arches or cut brick to fit.

Inwall.—In laying brick in the inwall it is customary to leave from 3 to 6 inches of space between the shell and brick work. This space is filled with mineral wool, granulated slag or loam. Mineral wool is considered to be the best possible material as it is elastic, non-conducting and does not pack. When granulated slag is used it is mixed with about 25 per cent. of loam. Many furnaces use loam or broken bats for filling.

Top Brick.—Some furnace managers prefer blocks in the top of the furnace instead of the usual 9-inch and 13½-inch sizes. There is a difference of opinion as to the advantage of block linings over 9-inch and 13½-inch linings.

Blast Furnace Stoves.—The manufacture of brick for blast furnace stoves presents difficulties equally as great but different from those belonging to the manufacture of brick for furnace linings. The destructive action of the gases on the bond of the brick, the variation in temperature many times in 24 hours, the grinding and pressure due to internal movement, combined with the heat generated by the combustion of enormous volumes of furnace gases create very severe conditions.

The essential qualities in blast furnace stove brick are capacity to absorb heat readily from the combustion of the waste furnace gas and readiness to give off this heat readily to the air that is forced into the stoves.

The quality of the clay, the mix and the method of manufacture must be such that the bond between the particles will resist the disintegrating action of the blast furnace gas and maintain the strength of the brick under the weight of the superimposed brick work. It is also necessary that they have a large margin of refractoriness to withstand the prolonged service expected. This is very important for the reason that as the dust collects in the flues and on the dome the heat absorptive and radiating capacity of the brick work is very

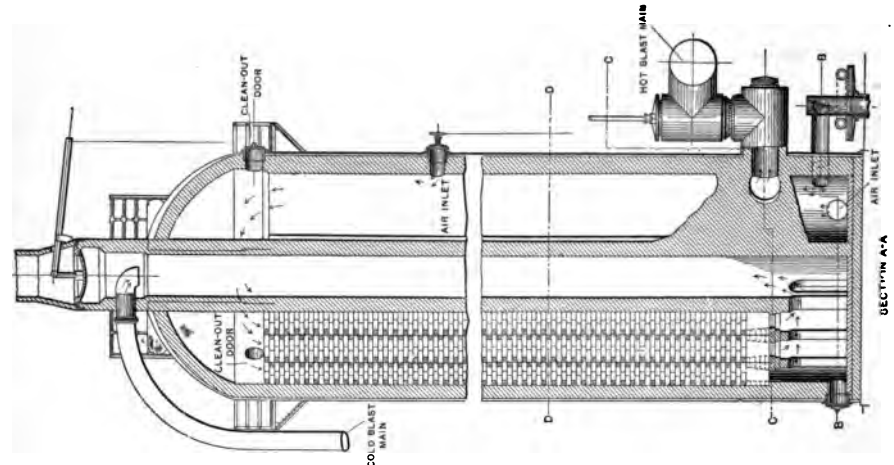


FIG. 211.

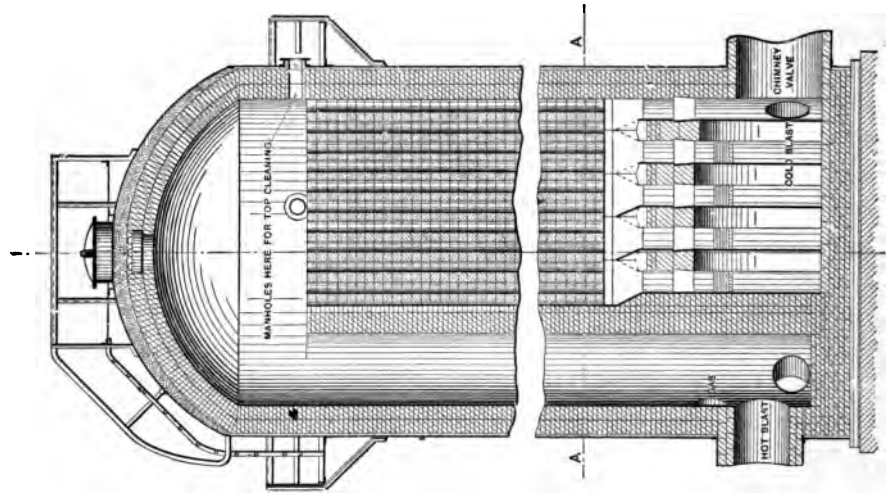


FIG. 210.
TYPES OF STOVES.

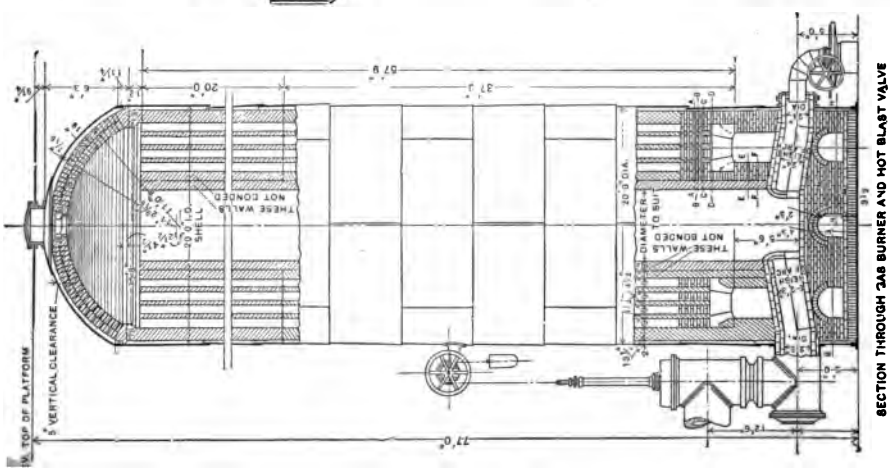

TOP OF PLATFORM
VERTICAL CLEARANCE
THESE WALLS NOT BONDED
THESE WALLS NOT BONDED TO SHELL
SECTION THROUGH GAS BURNER AND HOT BLAST VALVE

FIG. 209.

materially decreased, and a furnace man may find it necessary to push the stoves. This dust is quite fusible and naturally attacks the brick work and the less refractory the brick are the more they are attacked. Another important quality demanded is that the brick should not scale off in service.

The space which it is necessary to leave between the shell and the brick work need not exceed 2½ inches as the temperatures in the stoves are less than those of the furnace. High authorities in construction advise that beneath the lower courses of the brick in the hearth of the stove there should be at least one inch of cement, and that the space between the shell and the jacket for six feet from the ground be grouted with cement. The lower portion of the shell of the stove rusts out and this grouting of cement prevents the escape of the gases from the lower part of the stove.

In a stove 100 feet high the brick will rise several inches. Allowance should therefore be made for expansion. There is unquestionably a tendency to insist upon higher quality in both No. 1 and No. 2 quality stove brick. Modern conditions have made this necessary and there are few blast furnace managers who do not realize that the temperature of stove brick is a matter demanding the possession of high grade clays, full understanding of the conditions prevailing in stoves, and an organization and capacity to make brick in the manner in which they should be made. To meet this demand the most progressive manufacturers are using only selected hard and plastic clay and are using a greater portion of flint clay than was formerly employed in brick for stove linings.

A point that is sometimes lost sight of is the importance and advantage of having all the brick that go into a stove come from the same district and made from clays of a uniform and similar character. There is the greatest possible difference between clays of one district compared with those of another, in their behavior under the conditions and heat in stoves; and to use first quality stove brick from one district and second quality stove brick from another, may result in serious consequences.

The brick work in a well-designed stove should last for a good many years. Of course during this time the combustion chamber will be renewed several times and also the brick around the hot blast valves, etc.

Open Hearth Furnaces.—The open hearth furnace is a regenera-

tive gas furnace in which pig iron, wrought iron, steel, steel scrap, etc., are exposed to the direct action of the flame and converted into steel. Theoretically the regenerative principle is unlimited in its capacity for increasing temperatures. Practically it is limited by the refractoriness of the materials used in the construction of the furnaces, regenerators, etc.

The necessity, combined with the advantage, of running open hearth furnaces at the highest possible temperature render essential the use of the most refractory substance commercially obtainable.

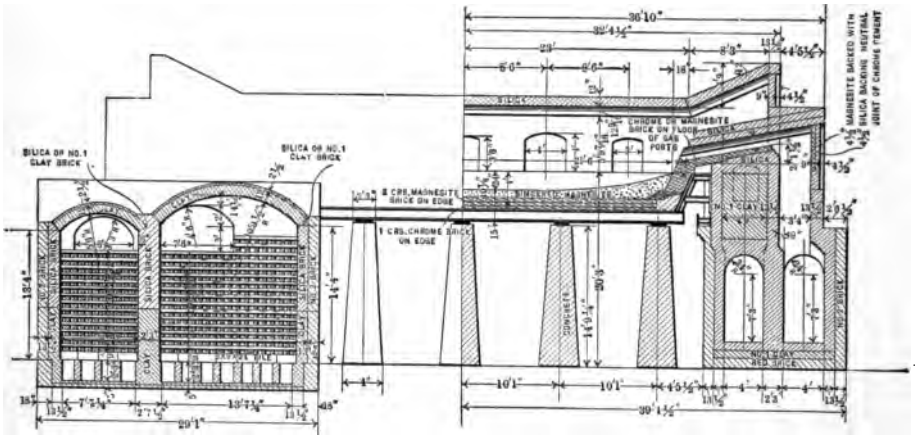


FIG. 212. BASIC OPEN HEARTH FURNACE, SHOWING BRICK FOR VARIOUS LOCATIONS.

The regenerative principle with its almost unlimited temperature possibilities demands the utmost care and intelligence on the part of those responsible for the operation of open-hearth furnaces.

From the point of view of the manufacturer of refractory materials the basic open hearth furnace is of great interest. There are many more basic than acid open hearth furnaces, and the basic furnace is a consumer of practically all of the different refractory products that are manufactured on a commercial scale.

Fig. 212 showing a basic open hearth furnace illustrates the use of different classes of refractory material in different portions of the furnace. It will be noticed that directly over the steel plate forming the bottom, are laid courses of silica brick or clay brick of the highest quality. There may be three or four courses laid on the flats and joints broken, or one or two courses laid on edge with the joints

broken. Over these courses come chrome brick, either on the flats or on the edge. Over the chrome brick are several courses of magnesia brick on edge, and then magnesia brick on their flats.

On this solid foundation of basic and neutral brick a magnesite bottom is sintered in at the rate of about 12 bags every four hours, averaging one-half inch at a time over the whole hearth. The rate at which the magnesite bottom is made depends of course on the heat in the furnace. The finished bottom averages from 15 to 24 inches thick with a probable average of about 18 inches. Basic slag is mixed with the magnesite in the proportion of from 10 to 20 per cent.

It is of course understood that in the basic as well as the acid process, the hearth is only a passive agent. It is simply the retort in which the metallurgical and chemical work is carried on. It is of interest to note that various substances other than magnesite have been used to make furnace bottoms, such as carbon, bauxite, chromite, lime and dolomite. Doubtless magnesite is the best material for the basic hearth. When properly put in the cutting by slag is very slight. Chromite, or oxide of chromium and iron, usually referred to as chrome ore, is one of the most infusible of substances and one of the best to resist both acid and basic substances. It is very difficult to fuse or sinter it into a solid impenetrable mass but it is within the bounds of possibility that chrome ore may find a useful field in making furnace bottoms, in addition to its present use in open hearth furnace practice. Heretofore its unsatisfactory mechanical structure has prevented its employment in this manner.

Practically every furnace bottom when broken up shows that melted metal has penetrated through the cracks and found its way to the enclosing shell containing the hearth. The vital necessity therefore of an ample foundation of basic brick, and of first class bricklaying with tight joints and joints properly broken, is apparent as a preventative of break outs. The bottom shell should be tightly riveted so that when the molten metal finds its way to the plate work, it cannot find an outlet but spreads over the bottom and finally chills. A loose rivet or improperly riveted joint invites trouble from break outs.

The roof and side walls should be built of the highest quality of silica brick. A good many large modern furnaces of fifty tons or over have 12-inch brick in the walls and roof. A thick wall and

roof prevent excessive radiation. Too great radiation means a long exposure of the charge to the gases, occasions increased loss by reason of greater oxidation and has other obvious disadvantages.

The kind and quality of brick which should be used in the uptakes, regeneratory chambers and other portions of the furnace are well shown in Fig. 212. The portions of the open hearth furnace in which the heat regeneration is performed demand intelligence and judgment in the selection of the brick with which they are to be built. In some cases the importance of this matter is not given the attention necessary to insure the best and most economical results.

It is very essential that checker brick have the proper physical structure to absorb and give up heat readily. High grade refractory clay checker brick last two or three times as long as inferior or less refractory brick, and the percentage of high grade brick that can be used over again after cleaning checkers is much higher.

Producer gas is harder on brick than is natural gas. It is more variable in composition and carries a good deal of dust. This entails more frequent cleaning of checkers. Where the practice is severe and the heat in the checkers intense silica brick are sometimes used in the upper courses of the checkers. Magnesia brick have also been used with advantage in the upper courses of the checkers in some cases, where the dust, oxides, etc., carried over by the flame are especially destructive. The brick manufacturer who has gone into this subject thoroughly with a large proportion of the open hearth managers and superintendents whose practice and methods are recognized as being the best, alone realizes how important this matter is to the economical and successful operation of the furnace.

There is no furnace employed in metallurgy in which the economy of using only the very highest grade materials is so pronounced as in the basic open hearth furnace. Only brick of the very highest refractoriness are capable of withstanding the intense heats. The heat action is intensified by the scouring nature of the slag and also by the character of the deposit carried over by the gases into the chambers and flues. This deposit consists of sand, dirt, rust, scale, lime, ore, etc. Fine globules of metal are thrown up from the bath by the violence of the carbon reaction. These particles are immediately oxidized and the deposit therefore consists largely of finely divided iron oxide. This is exceedingly fusible and destructive of the brick work.

It is absolutely essential that the design of the open hearth furnace be a correct one. No brick will stand for any length of time in a poorly designed furnace. An impinging flame rapidly destroys the most refractory brick, while the same brick will withstand an equal amount of radiated heat for a prolonged period. Any unusually rapid cutting out of a particular portion of a roof or wall may be set down to an impinging flame.

The necessity of heating up slowly all furnaces in which silica brick are used is occasionally lost sight of, especially in times of pressure for output. It has been proved beyond all question that the refractoriness of silica brick is reduced several hundred degrees by too rapid heating. Silicia brick are very tender and susceptible to changes of temperature, and the utmost care should be used in heating them up slowly, evenly and continuously. The same care should be used in cooling down when the furnace is put out of commission. At least six to eight days should be taken and many furnaces take from ten days to two weeks, to bring them up to charging heat. It is undoubtedly true that the longer time is an advantage to the silica brick, whatever may be the objections from other points of view.

Silica brick should be laid dry. In the walls they should merely be trued up by dry ground silica. In the roof they should be grouted in with finely ground silica mixed with water to a thin soup and poured in between the joints.

Magnesite and Chrome.—The great importance of magnesia and chrome refractories to the iron and steel industry makes a chapter on them desirable. White magnesite is produced in small quantities in California and there is a large production in Greece. A small tonnage is shipped from India and South Africa. There are deposits in Swedish Lapland, Norway, Canada, Russia, New Caledonia and elsewhere.

White magnesite is not used in iron and steel furnaces to any extent and none of the magnesite found in these localities is of particular interest to the iron and steel trade which draws its supplies from the deposits in Austria-Hungary, and more particularly from those found about 250 miles north of the port of Trieste on the railway between Vienna and Trieste. Here the quarries of magnesite are developed in the most intelligent manner. The main body is about 6,000 feet long, and 600 feet deep and of varying

width, depending upon the shape of the mountain. There are six benches running around the mountain from which the raw material is quarried. About 700 men are employed at the main quarry.

The quarried material must be very carefully selected as there are small veins of silica and dolomite slips running all through it and only an experienced eye can tell the difference. Nothing but lumps weighing from 5 to 30 pounds are sent to the kilns. There is a waste of 60 per cent. of the material in quarrying, and every-

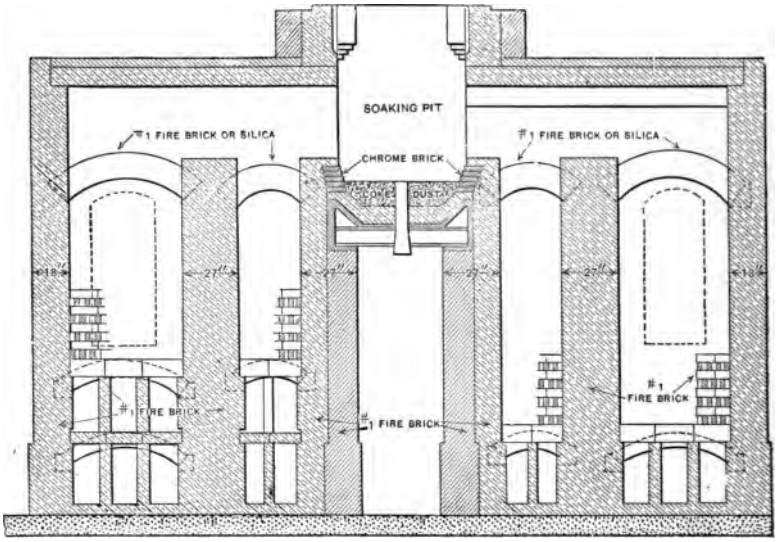


FIG. 213. SECTION OF SOAKING PIT, SHOWING LOCATION OF VARIOUS QUALITIES OF BRICK.

thing is hand selected, no fine stuff being sent to the kilns. The quarried material loses about one-half its weight in calcining. About five tons of rock are quarried to produce one ton of dead burned magnesite.

There are between 500 and 600 hands employed in the calcining department. After the magnesite has been dead burned and has laid for several weeks it is crushed and dropped on to revolving sorting tables where it is again hand picked. The high price of coal, which ranges from $5.75 to $8.00 per ton at the kilns, is a serious item in the cost of preparation of dead burned magnesite for the market, as well as the cost of shipping to port, handling, sacking, ocean freight, insurance, etc.

The first Austrian or Styrian magnesite brought to the United States was a shipment of 800 tons bought in Europe in 1885 and the first basic steel in the United States was made in 1886. As practical experience was gained it was proved conclustively that the Austrian magnesite was the best for making basic bottoms. Its composition gives it the very valuable quality of fritting or setting at open hearth temperatures. Its low silica and lime contents,

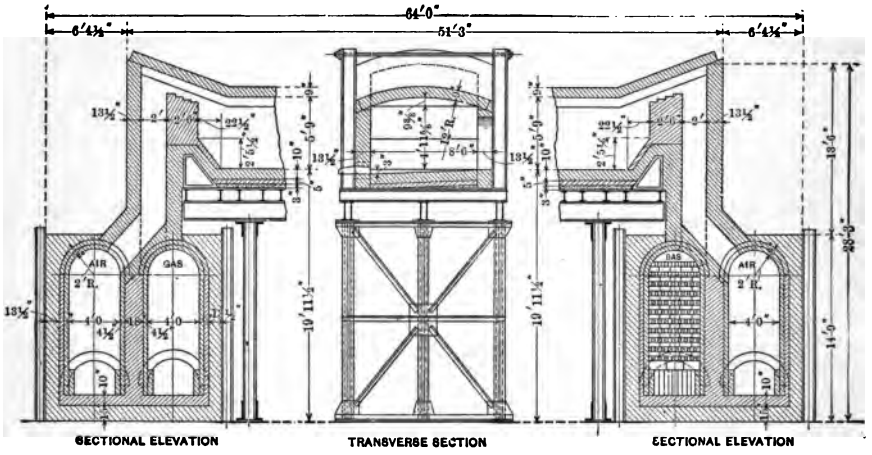


FIG. 214. SECTION OF GAS HEATING FURNACE.

careful preparation and uniformity make it the most satisfactory and economical magnesite.

The method of sintering the magnesite bottom into basic open hearth furnaces has already been described. When of the proper quality and properly put in it should last for years. There are records of bottoms that have been in for more than eight years and from which over 6,600 heats have been taken, and they are still in good condition.

The principal advantages of magnesite bottom compared with other materials are: (1) Its longer life and greater dependability. (2) The fact that its chemical composition enables it to resist better than any other material the action of basic slag. (3) It is practically unaltered by exposure to the atmosphere unless this exposure be unduly prolonged. It may then absorb moisture and carbonic acid gas to a small extent. (4) It is not liable to rot and break up by absorption of metal and slag. (5) It can be used over

and over again. (6) Many more heats of basic steel can be made on magnesite bottom than on any other bottom before renewal is necessary. (7) Repairs are relatively small and unimportant and can be quickly performed. (8) It agglomerates well and patches do not come up to the surface. Patches of their basic bottom on the surface of the bath would retard the operation. (9) Magnesite can come in direct contact with silica brick without danger of fusion.

Several patents have been taken out for making the furnace block of magnesite and considerable success is claimed for one or two methods of using magnesite in this portion of the furnace. Dolomite is used to a considerable extent in making furnace repairs but it is not nearly as efficient and valuable a refractory as magnesite. With basic as well as with other classes of refractory material the best and most durable is usually the cheapest in the end.

In open hearth furnaces magnesite bricks are used in the bottom as described in another part of this chapter. They are also used in the ports, in the jambs and around the tapping hole. Magnesia bricks have been used in the upper portion in the backwall of the uptakes where the flame carrying over the dust, oxide of iron, etc., strikes the wall. Six or eight upper courses of magnesia are put in the checkers at some plants and it is stated that repairs and renewals to checker work are cut down. As the valuable qualities of magnesia brick become better understood, their use is bound to increase.

In the furnaces used in the manufacture and treatment of iron and steel they are used in the six or eight courses of soaking pits; in the bottom and bridge walls of continuous gas billet heating furnaces; in the bottoms and around the top holes of coal fired heating furnaces; in puddling furnaces over the chill; in the bottom and sidewalls to the slag line of mechanical puddling furnaces; on the metal slag line of metal mixers; on the bottom of small riveting and heating furnaces; in dolomite calcining kilns, etc.

It is of interest to note that magnesia brick are much better in quality than they were a few years ago. The greater experience of the manufacturers and better knowledge of the conditions under which they are used has gradually brought this about.

Chrome Ore and Chrome Brick.—The best chrome ore for use as a refractory is found in Greece. Deposits of chrome ore are also

being worked in California, Turkey, New Caledonia, Canada and elsewhere. The manufacture of chrome brick requires a great deal of care and attention.

Chromite was first tried in its natural state as a refractory in 1879 at the Petersburg Alexandrofsky Steel Works in St. Petersburg, Russia. It is exceedingly refractory and neutral in character; being neither acid, basic, reducing or oxidizing. Heated in lumps it does not crumble or decrepitate, however high the temperature. In the open hearth furnace, chrome ore is used as a neutral to separate the silica brick from the magnesite, and also in paving floors of ports and as a protection to the walls of the gas ports. Other places for it are as a protection to the bulkheads and especially on the bank of the furnace under the back wall. At some plants it is mixed with magnesite in making the stopper for the tapping hole. A well known open hearth superintendent uses it as a wash for the checker brick. At plants having tilting furnaces it is used on the skew-back line of the furnace. It has also been employed to patch up jambs where the charging machine cuts out silica and magnesia brick.

Chrome brick are used in the bottom of the open hearth furnace as previously described. They have proved economical in the six or eight bottom courses of soaking pits, and are also used in the same wall as magnesia brick in some heating, puddling, scrap and other furnaces and also in metal mixers, calcining kilns, etc.

It may be put down as a general rule that magnesia or chrome brick will prove economical in any place in any kind of iron and steel furnace where basic or scouring slags cut out fire clay or silica brick rapidly.

Soaking Pits.—The intense heat in the pits and the fact that there is very little radiation demand the use of very high grade refractories. The use of fire clay wedge brick, 13½ to 18 inches long, in forming the arch is preferable to building them of the regular 9-inch shapes, as the large brick have a better bearing and diminish the possibility of distortion and falling in of the arch. Some furnace superintendents are using silica brick in the arches over the ports, laying three 4½-inch courses. Very satisfactory results have been obtained, as the silica arches hold their shape in an excellent manner. The clay brick piers are built after the arches are laid and the arch does not bear on the piers. It takes from 30,000 to 40,000 brick to build a soaking pit, including the checkers.

The use of magnesia or chrome brick in the six or eight lower courses of soaking pits has proved a decided economy. The slag which collects in the bottom of the pit cuts out clay brick rapidly, allowing the walls to fall in. Magnesia or chrome brick obviate this trouble.

Continuous Gas Heating Furnaces.—Fig. 214, showing a gas heating furnace, illustrates the various uses of refractories in furnaces of this type. Conditions are very severe, very high heats being reached. Some large plate mill heating furnaces are built of silica brick and very satisfactory results are claimed. Many furnaces have been built of quartzite brick and they are giving excellent service.

Bessemer and Tropenas Converters.—Compared with the open-hearth furnace the Bessemer converter is a very small consumer of refractories per ton of output. The question of getting good tuyeres is frequently a serious one, and not every manufacturer can turn out well fitting blocks for the bottom. Silica brick make the best lining for Tropenas converters and the proper grind and burn of the brick are important in securing the best results.

Malleable Furnaces.—In no other type of furnace is the cost of refractories per ton of output greater than in malleable furnaces. The service is exceedingly severe, and in the bungs especially only the very highest grades of fire clay brick of uniform quality will meet the conditions.

The reasons for the very rapid destruction of brick may be summarized as follows: Intense heat is attained by the use of good flaming non-coking coal burned under draft or blast pressure. There is an excess of heat in the furnace over that required to melt the charge, and an excess of fuel over that employed in other types of melting furnaces, partly because of certain advantages to the malleable iron manufacturer, and partly by reason of the class of material charged. Another reason is the fact that furnaces are charged full or almost full up to the roof. This has the effect of throwing the flames and heat directly against the brick in the bungs and elsewhere. It is a well-known fact that an impinging flame burns out brick work much more readily than does radiated heat. The removal of the roof (bungs) in order to charge, while the brick are almost at the working heat of the furnace, is also damaging to the brick. Practically no brick known will stand this without

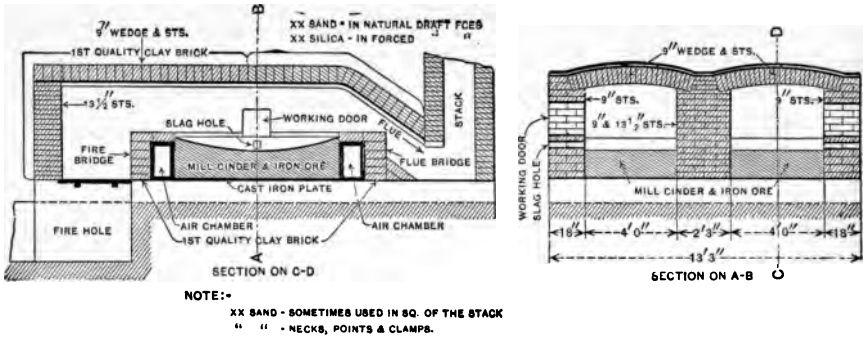


FIG. 215. PUDDLING FURNACE, SHOWING LOCATION OF VARIOUS QUALITIES OF BRICK.

more or less spalling. Bringing up heats quickly is also exceedingly hard on all classes of brick work.

In order to obtain the best results the brick in the bungs should be laid dry, and then grouted with a very thin fire clay cement, rubbing and fitting to insure a brick-to-brick joint. They should be laid evenly without any one brick projecting beyond its fellows.

It is impossible to emphasize too strongly the value of first class bricklaying. If one brick projects downwards from a roof lower than its fellows, it catches the heat and burns or spalls off. If, in breaking off, it breaks above the level of the brick laid next to it, the hole causes a swirling flame which soon burns off the brick sur-

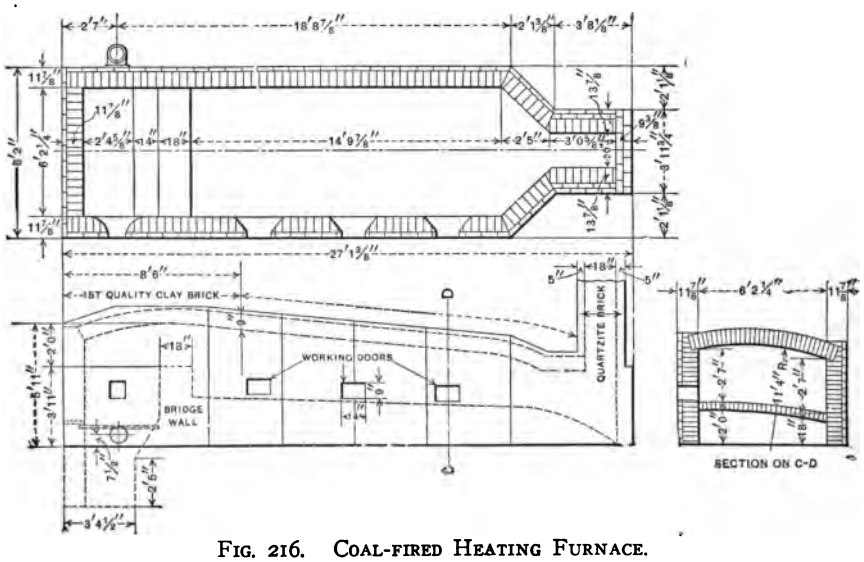


FIG. 216. COAL-FIRED HEATING FURNACE.

rounding the hole and the destruction of the roof proceeds rapidly.

The same clay as that of which the brick are made should always be used in laying them, and not more than 300 to 350 pounds of clay to 1,000 9-inch brick. The brick should be kept dry both in the sheds and in the foundry. Bungs should not be put on wet floors when the brick are red hot. Brick that are used as soon as possible after taking from the kilns give somewhat longer service than if they have been stocked for some time, as all brick suitable for use in bungs are more or less porous and absorb moisture. When this moisture is driven out by the rapid heating up in the

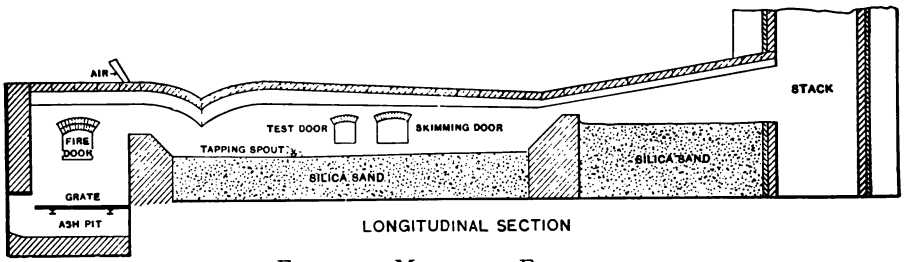


FIG. 217. MALLEABLE FURNACE.

furnace it has an injurious action on the bond of the brick, and makes them less tough and less able to stand the strain of rapid heating up and cooling down.

It is important to remember that brick of hard burn and fine grind should be used for the fire box walls and sides of the furnace as they will stand the wear in the fire boxes and the flow of metal and slag better than the lighter burned brick used in the bungs.

Some manufacturers have trouble because of their stack chambers burning out, especially where the stack is quite near the furnace, and where the flame, as it leaves the furnace, strikes the back wall of the stack. The use of a deflecting wall or any device which will give a rotary movement to the flames as they leave the furnace and enter the stack helps to save the back wall. An impinging flame is always very destructive of brick work and any plan that prevents it lengthens the life of the fire-brick.

Some manufacturers have devoted considerable throught and care to making special blocks for use in the annealing furnaces. The heat in the flues and the wear caused by wheeling the annealing boxes in and out makes it economy to use specially made blocks of special size, mix and burn.

Puddling Furnaces and Coal Fired Heating, Scrapping and Bushelling Furnaces.—Some of the illustrations show the approved construction and use of refractories in furnaces used in the refining and treatment of wrought iron. The roof over the fire box and the necks and squares and around the tapping hole require frequent

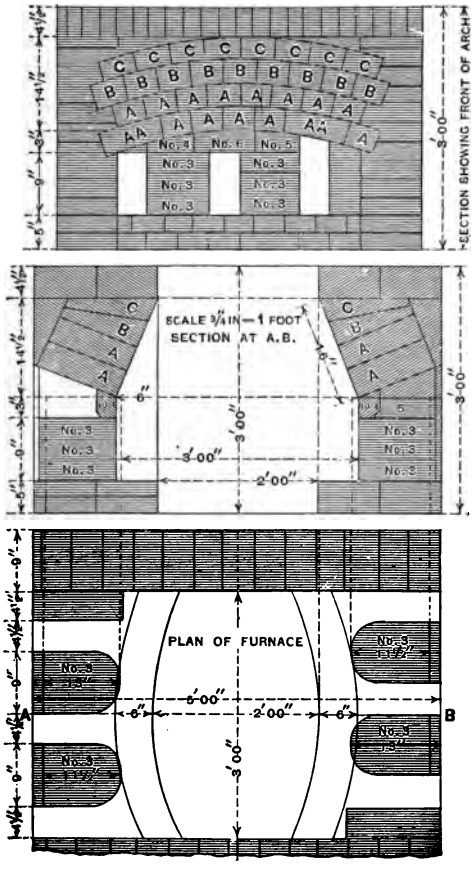


FIG. 218. CRUCIBLE FURNACE.

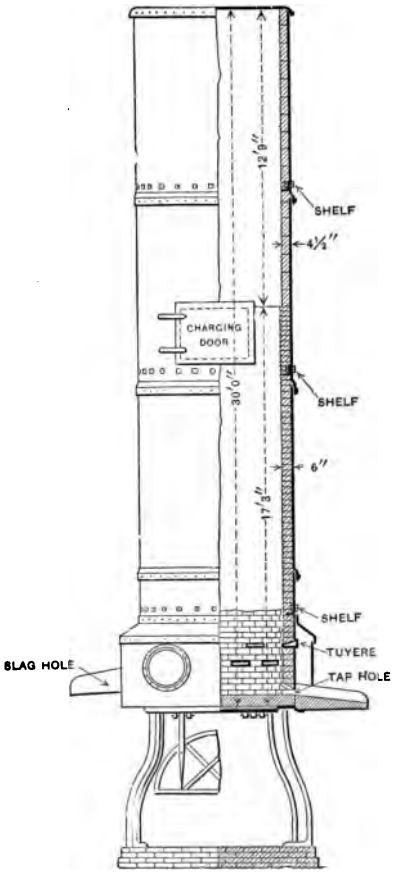


FIG. 219. HALF SECTION AND ELEVATION OF CUPOLA.

renewals and repairs, and here the economy of using only the highest grade and most suitable brick is most evident.

The use of draft or blast or of steam increases the severity of the working conditions and makes the use of the highest grade brick imperative, if true economy in the use of refractories is to be reached.

Electrical Furnaces.—The rapid increase in and successful operation of electrical furnaces during the past few years makes an article on refractories incomplete without at least some brief mention of them.

Magnesia brick or chrome brick are practically indispensable in lining these furnaces, and it is very interesting to note the continually widening use of basic refractories in the various types of electrical furnaces devoted to the production of ferro-alloys and the finer grades of steel. Where dead burned magnesite is used in lining electrical furnaces it is mixed with 12 per cent. of tar. About three tons of magnesite are required to line the usual type of electrical furnace now in operation.

Some Practical Hints.—The building of different parts of furnaces has an important bearing on the life. Suitable shapes of brick which are in practical use in building and repairing walls, ports, arches, etc., in the least time and with the smallest amount of cutting should be used. Complicated or difficult shapes should be avoided as much as possible. These cannot be re-pressed, are more liable to irregularity and cracks and are not as strong as regular standard shapes.

All brick should be kept dry and handled carefully to avoid scuffing and cornering. They should be laid with the smallest possible joints. Not more than 300 to 350 pounds of ground clay, etc., should be used to lay 1,000 9-inch equivalent. Brick joints should be properly broken. The more symmetrical an arch the stronger it is.

The brick of greater taper should be placed towards the center of the arch. Straights and taper brick should interchange as much as possible, and two straights should be avoided.

All brick work should be heated up and cooled down slowly and evenly. The use of high grade refractories and an observance of the instructions given above will banish or diminish many of the troubles inherent in the operation of furnaces at the intense heats demanded in the manufacture and treatment of iron and steel under modern conditions.

APPENDIX.

I. PURIFICATION AND RECOVERY OF GASES.

Separation of Gases from Solids.—The removal of dust from gases is quite an important metallurgical and chemical problem, which can be solved in different ways. In all the processes used for this purpose, however, it is necessary to cool the gas before separation can be effected. In some cases a simple cooling is sufficient to remove the dust nearly completely. Such a gas-cooling apparatus is shown in Fig. 220. It consists of a sheet-iron channel

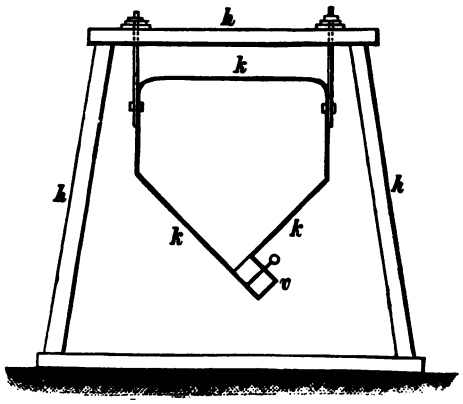


FIG. 220. COOLING APPARATUS.

K. The dust collects upon the bottom of same and is removed through openings *v* provided in certain distances.

Filtration is frequently employed for collecting dust, which is contained in gases in a finely divided state. In the manufacture of zinc oxide, for instance, the air containing the oxide is filtered through bags in which the solid particles are retained.

A decrease of the velocity of the gas current also facilitates the separation. For this purpose the gases are led into chambers or channels before they are allowed to escape through the stack, as decrease of draft is not nearly as effective as frequent and continued contact with large surfaces; narrow channels are more advantageous than large chambers.

Another way of causing separation is the change of direction of the gas current, which is the more effective the cooler the gas. Zig-zag shaped channels are used for this purpose.

For removing the dust from blast furnace gas, wet processes are almost exclusively used. In the Zschocke system the gas is washed in scrubbers, which are so constructed that they cannot be clogged

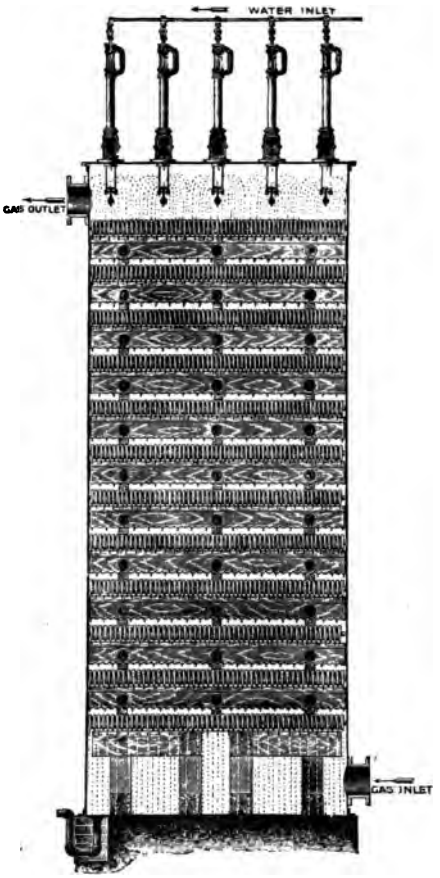


FIG. 221. ZSCHOCKE SCRUBBER.

up by the dust. Fig. 221 shows a sectional view of such a scrubber, Fig. 223 illustrates the arrangement of the scrubber filling. Fig. 222 shows a plant during erection.

An effective method for removing solids from gases is the application of a fine spray of water whereby the dust is precipitated.

Fig. 224 shows one of the spray nozzles as they are manufactured by the Schutte and Koerting Company, Philadelphia, Pa. They are made for various applications, according to the pressure of the liquids to be atomized; further, according to the diameter of the orifice and the form of the spray, any or all kinds of effects may

FIG. 222. ZSCHOCKE PLANT IN COURSE OF ERECTION.

be accomplished. The working of these nozzles is clearly shown in Fig. 225.

In the cut, which shows the arrangement of the Koerting glass or platinum spray nozzles, the water enters at *P*, passes through the filter *F*, and from there through the float valve *B* into the tank from where the pump takes the water, forcing it under sixty pounds pressure to the nozzles installed on the top of the chamber. Each nozzle is protected by means of a separate strainer, which is necessary on account of the small openings.

The application of these nozzles for removing and precipitating dust is shown in Fig. 226. The air or gases enter at *E* and are discharged at *A* completely cleaned. The air is forced through the dust collector by jet ventilators or rotary fans. The precipitating of the dust and vapors is done by means of nozzles. The pressure

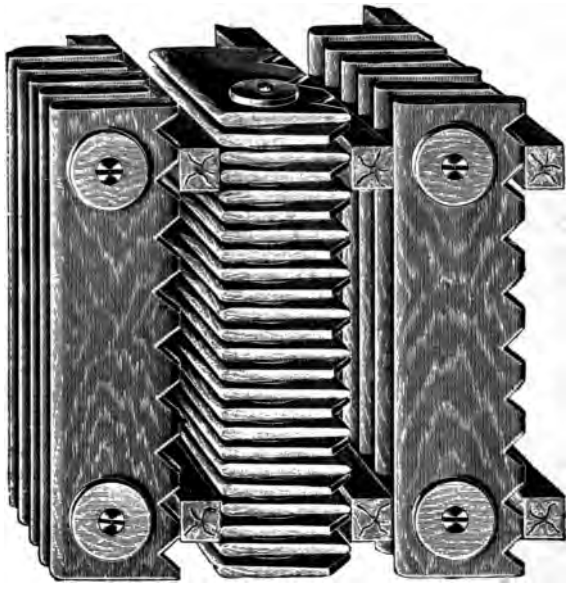


FIG. 223. SCRUBBER FILLING.

water for the nozzles is carried to the apparatus after it has passed the strainer *S*. The water is discharged through pipe *L*. These dust collectors have proven very satisfactory in various industries.

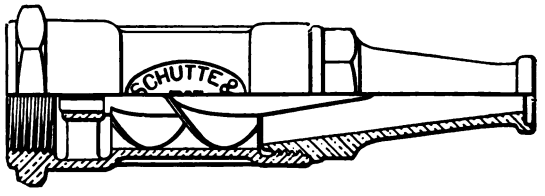


FIG. 224. SPRAY NOZZLE.

In connection with grinding installations, where dust is to be collected in a dry state, without the use of sieves, so called air separators are used.

In the separator of Mumfort and Moodie, shown in Fig. 227, a

ventilator E is provided upon the vertical shaft E_2. The latter carries also the distributing plate S, the object of which, as the name implies, is to distribute over its periphery the material to be separated. By a system of rings, disks and cones, the air drawn in by the ventilator is forced through the material which is constantly falling down in the shape of a bell. The air current carries the fine, dusty particles along and enters the ventilator, the mixture

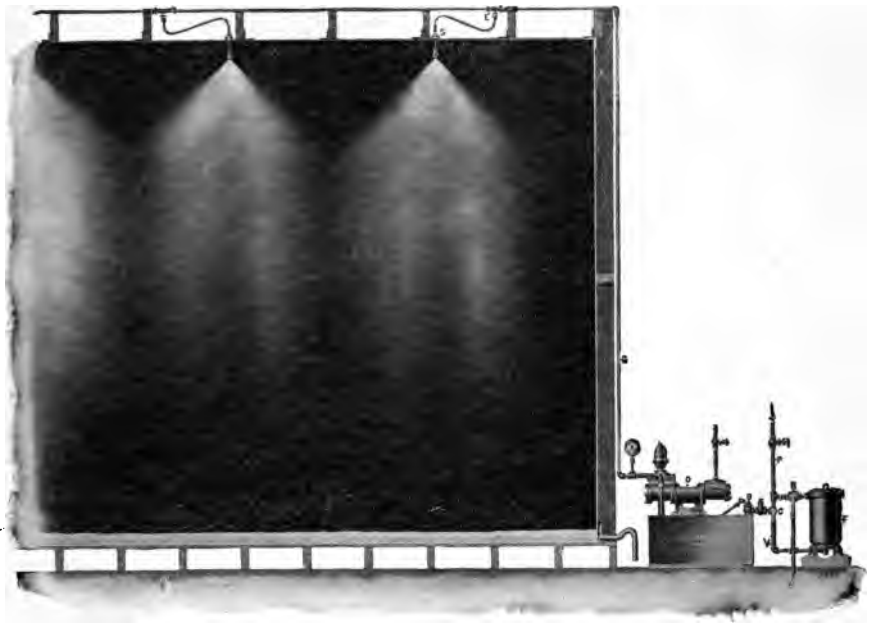


FIG. 225. APPLICATION OF SPRAY NOZZLE.

being thrown against the wall of the cylindrical tank A. The fine particles are carried to the bottom by the air current. The coarse parts not carried along by the air current fall into the interior cone B and may be retransported to the mill through pipe a, while the separated fine product falls into the space between housing A and cone B, and is removed from here by hand or screw conveyer.

A vacuum separator which is successfully used in connection with any form of grinding mill, the material being elevated and discharged into the hopper of the separator in the same manner as to a bolting reel, is shown in Fig. 228. In this apparatus the material is fed automatically into the center of the tailing spout, above where the return air enters.

Separation of Gases from Liquids. If it is desired to separate gases from liquids in which they are absorbed, the process to be applied will be different according to whether the gas liberated is to be used or wasted. In the former case a distilling apparatus with condensing cooler will have to be used, while in the latter case

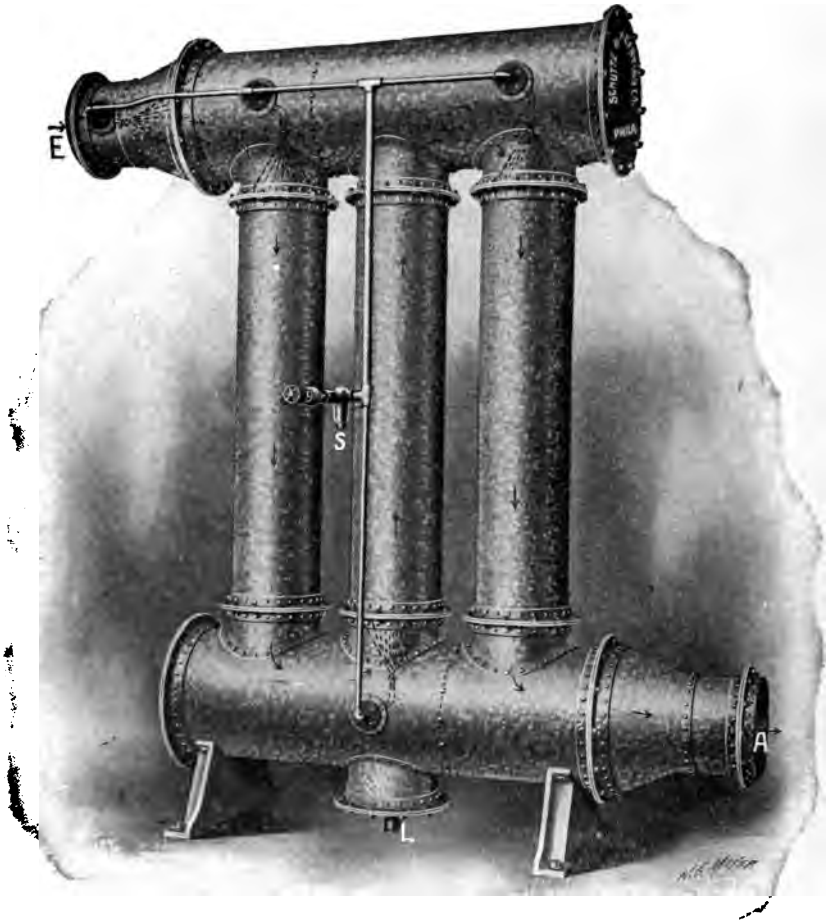


FIG. 226. REMOVING DUST BY MEANS OF SPRAY NOZZLE.

an evaporating apparatus can be applied. Gases that are absorbed by liquids at high temperatures can be conveniently separated by cooling the liquid. An apparatus which is successfully used for this operation is Mohr's cooler, Fig. 229. It consists of zig-zag shape pipes, containing in the interior cooling pipes of the sampe shape.

The outside pipes *A* are connected at the top and the bottom by so-called connecting boxes; in the bottom boxes outlet openings are provided for the liquids separated.

Öf entirely different construction are the apparatuses which are built by Schutte and Koerting, Philadelphia, Pa., for absorbing gases

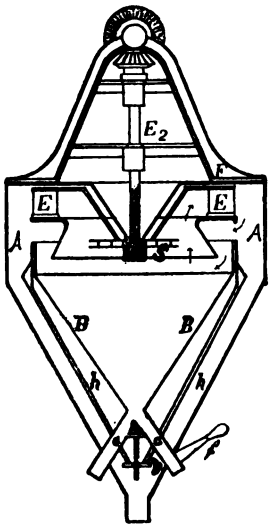


FIG. 227. SEPARATOR OF MUMFORT AND MOODIE.

FIG. 228. VACUUM SEPARATOR.

and condensing vapors. Here an extremely fine spray of water, produced by the above described spray nozzles, is applied to the gas mixture. Fig. 230 shows an installation of this type for the absorption of hydrofluoric acid gas. A hood is placed over the pit and is connected to a wooden tower, to the top of which spray nozzles are attached. The vapors free of hydrofluoric acid gas pass through the outlet to a chimney or fan.

An arrangement of the same type for condensing foul vapors is shown in Fig. 231. The fumes are sucked off by means of a water jet exhauster and pressed into the absorption chamber, in which spray nozzles are installed, which treat the gases on their way up and down in the chamber, the latter being equipped with proper partitions.

In order to illustrate the recovery of gases a Koppers improved ammonia recovery plant, as installed at various coke plants, is shown in Fig. 232.

The gases are passed through an acid bath, and the use of water for scrubbing purposes is dispensed with. The new method is described as follows:

The usual process for purification of the gases consists of subjecting them, first of all, to a cooling operation, and then passing

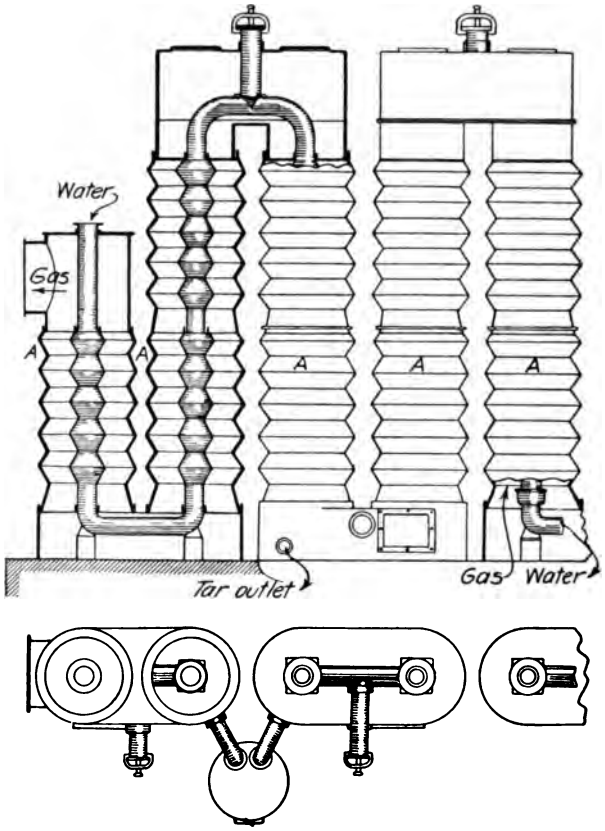


FIG. 229. MOHR'S COOLER.

them through washers for the extraction of ammonia. The gas upon leaving the ovens passes through air and water coolers, in which the larger portion of the tar and a portion of the gas liquor condense. It is then drawn by an exhauster, by which it is forced through tar extractors and ammonia washers. The ammonia washers are designed on several systems. Some being of a revolving description, while others are stationary and are not mechanically operated. The principle upon which they all work, however, is the

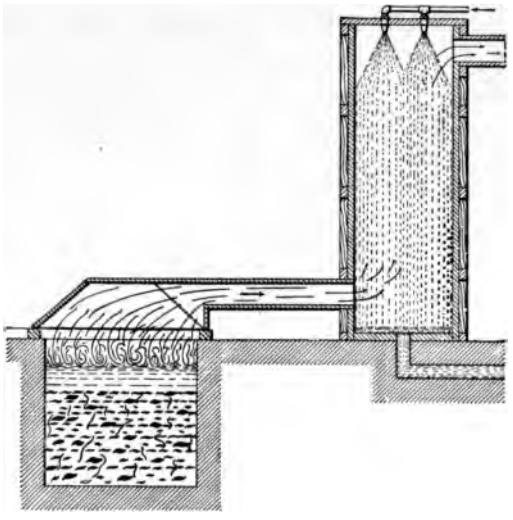


FIG. 230. ABSORPTION OF HYDROFLUORIC ACID GAS.

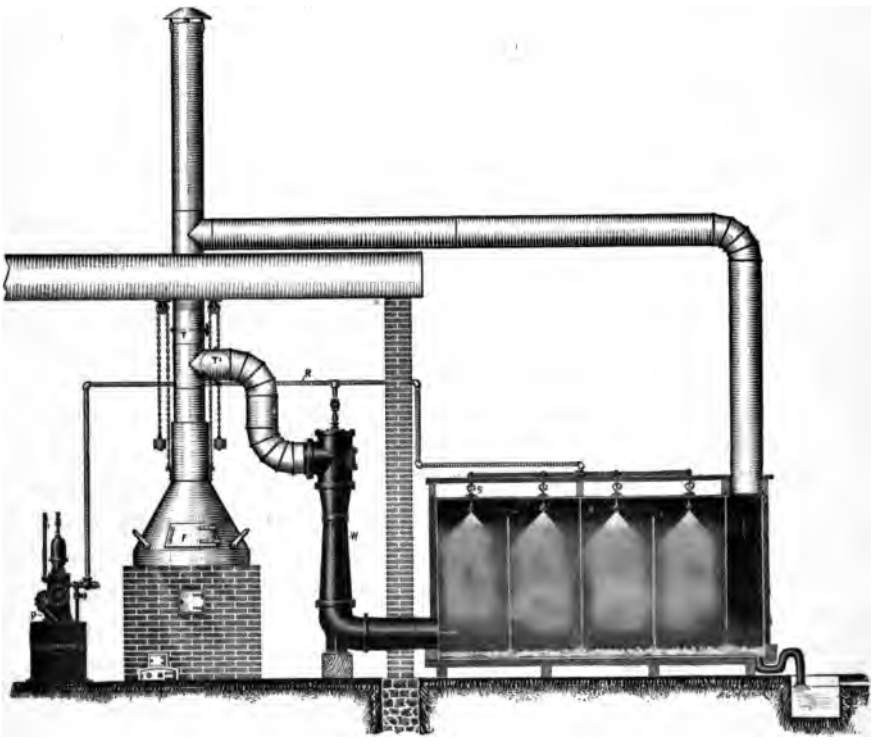


FIG. 231. CONDENSING FOUL VAPORS.

same—viz., that the washing liquor passes through the washers in the direction opposite to the gas, so that the enriched liquor comes into contact with the gas rich in ammonia, and the week liquor acts upon the gas when freed of most of its ammonia. It is necessary in order to obtain efficient washing for the washing liquor to be of a soft nature and quite cool.

The difficulty of constructing water tight tanks and keeping them tight, and also the difficulty experienced in disposing of the effluent from sulphate works have led to efforts to dispense with the washing of the gases with water, and a system was brought out some years ago, the object of which was to bring the gas into direct contact with sulphuric acid, in order to extract the ammonia without the scrubbing operation being necessary. This system only required a small collecting tank for the tar extracted in the hydraulic main, which was constructed of iron. Dispensing with the necessity for the employment of water for scrubbing (the provision of which at collieries in sufficient quantity, and at a sufficiently low temperature, frequently was a matter of difficulty), appeared to be a great advantage. The system consisted in conveying the hot gases, having a temperature from 130 to 160° C., in pipes carefully coated with non-conducting material and forcing the gas by means of an exhauster direct into a sulphuric acid bath. The tar separated out and floated on the surface of the acid, from whence it was skimmed or drawn off. The gas not having been subjected to a cooling operation, there were no products of condensation. As a consequence, the sulphate produced was contaminated with tarry matters which spoiled its appearance and deteriorated its quality. The tar itself was detrimentally affected, and was of an acid nature, it being necessary, in order to render it marketable, to purify it with hot water and to neutralize the acid with alkalies. It was also found that the saving in labor which was expected to be derived by the system was not realized owing to great cost involved in producing and treating the sulphate. In order to extract the tar from the hot gas, to overcome the difficulties referred to the gases were passed through centrifugal extractors. These machines, almost without exception, possess the drawback that they extract only the constituents boiling at a high temperature, and as a result a product of a pitchy nature is produced instead of tar.

The new system of Koppers is designed on the same principle,

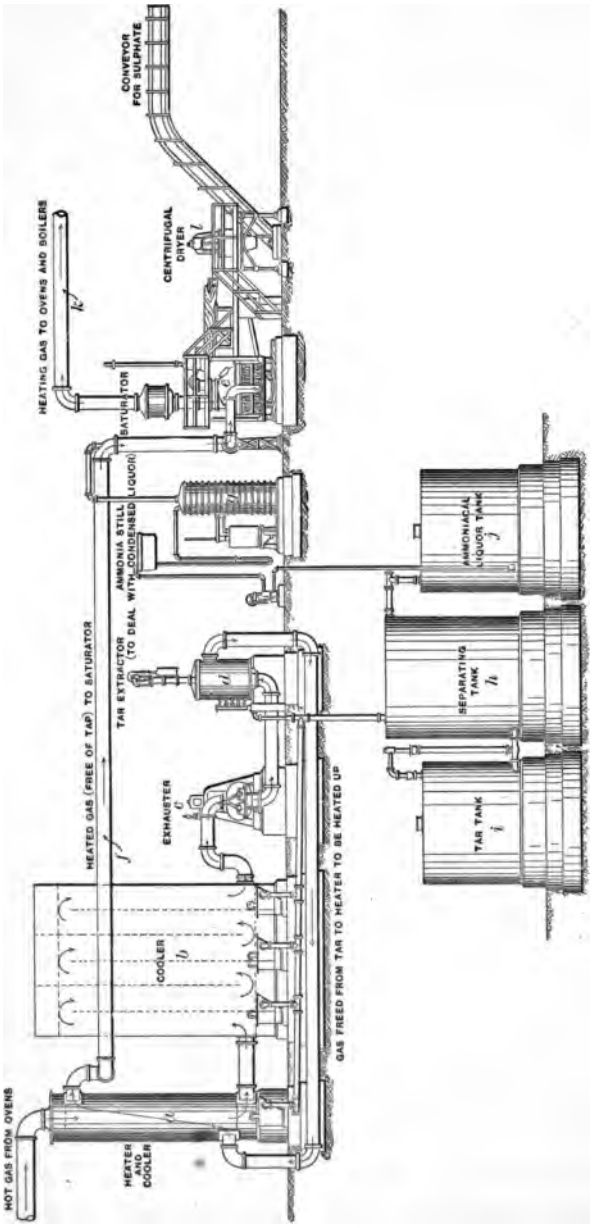


FIG. 232. THE KOPPERS BY-PRODUCT PLANT FOR THE RECOVERY OF AMMONIA DIRECT FROM COKE OVEN GASES.

but the gases are freed from tar before they are passed into the sulphuric acid bath. The gas is first of all cooled in order that the tar and gas liquor may condense. It is then passed through the tar extractor to take out the last traces of tar. After passing through the tar extractors the gas is led back to the preliminary gas cooler, which is arranged as a heat exchanger, and which heats up the gas to about 80° C. by the hot gases coming from the ovens. The gas heated up in this way and freed of tar is then conducted to the saturator, where the ammonia is extracted from the gas and recovered direct in the form of sulphate.

In the illustration, Fig. 232, a diagrammatical representation of the system will be seen. The hot gases of distillation pass first of all into what is called a heat exchanger *a*, and thence are conducted into water coolers *b*, by which the temperature is reduced to the degree which is necessary for the extraction of tar. As in the ordinary system, the gas, after cooling, is drawn by exhausters *c* and forced through the tar extractors *d*. After leaving the extractors the gas is conducted to the heat exchanger *a*, where it becomes heated up and at the same time cools down the hot gas as it comes from the ovens. The heated gas is then taken direct to a saturator, *e* where it comes in direct contact with sulphuric acid. Here the ammonia is extracted and is recovered in the form of ammonium sulphate. The gas after being freed from ammonia passes out of the saturator by the main *k*, by which it is conducted back to the ovens without necessitating any further cooling process, as is necessary where the ordinary system is employed. In the preliminary cooling process a large portion of the tar and of the gas liquor is condensed out of the gas. These products of condensation are conducted to the separating tank *h*, from which the tar overflows into the tar storage tank *i*, and the ammoniacal liquor passes into the storage tank *j*. The ammoniacal liquor is delivered to a distilling apparatus *g*, where the ammonia is driven off by means of steam and lime in the usual way. The vapor from the still containg the ammonia is conducted to the gas main, whence it passes with the gas into the saturator *e*. The sulphate formed in the saturator is collected in a well at the bottom, whence it is automatically removed by means of an injector, and it is then delivered into a centrifugal dryer *f*. The mother liquor extracted by the centrifugal flows into an intermediate vessel, whence it passes into the saturator. The acid is fed continuously into the

saturator, and the liquor therefore is always maintained at a uniform strength. The top portion of the acid in the saturator is thus kept at a slightly acid state, which insures the ammonia being thoroughly extracted from the gas.

It is only necessary for the gas to be heated before entry into the saturator to such a degree as will prevent condensation of the water vapor taking place in the saturator, so that the acid bath will not become diluted. The dew point of gas produced in gas retorts is about 70° C., while in coke oven gas the dew point is about 80° C. This is due to the coal used in gas works, being practically free from moisture. The coal used in coke works contains, on the other hand, a comparatively large percentage of water. It has been ascertained by actual experience that it is not necessary for the gas to be heated to a higher temperature than 80° C. before it is passed into the saturator. At this temperature it has been found that the sulphate is easily and efficiently formed. The ordinary method of producing sulphate requires the temperature of the acid bath to be maintained above 100° C., in order to prevent the steam from the still condensing in the saturator. The reduction of the temperature in the bath insures the complete combination of the ammonia with the acid, as the lower the temperature the greater is the affinity between the acid and the ammonia. At 140° C. the sulphate melts, and even at a much lower temperature than this it becomes decomposed.

A considerable saving in steam is effected, owing to the great reduction in the quantity of liquor which has to be distilled. A well designed ammonia still requires 300 kg. of steam to treat 1 ton of gas liquor. No water being required for scrubbing purposes, a saving is effected in this direction. Further, the quantity of liquor required to be distilled being greatly reduced, the effluent from the still is reduced correspondingly, which is an advantage where difficulty is experienced in disposing of this liquid.

The gas in passing through the acid bath becomes freed of all the alkaline matter it may contain. As a consequence of this the destructive elements which are the cause of the corrosion of gas meters, etc., are eliminated, as sulphuretted hydrogen and cyanogen combine with ammonia only in the presence of traces of alkalies. The ammonia washers being dispensed with, no pumps are required for dealing with the scrubbing liquor. Steam is hereby saved and also labor. Naphthaline deposition, it is claimed, is done away with.

The heavy hydrocarbons contained in the gas are not affected by the acid, so that no loss will be occasioned in this direction, while the calorific value of the gas remains unchanged.

The saving which it is claimed would be derived by the new system is put at about eight cents per ton of coke produced.

II. GAS POWER.

Gas Engines.—On account of the higher efficiency of gas engines as compared to steam engines it is frequently of advantage, even though in many factories steam is always available, to use gas power. In connection with producer gas the combustion engines present the cheapest means of generating power, since in a gas producer an efficiency of 80 per cent., in a gas engine of 26 per cent. is easily obtained, so that by this system it is possible to generate one horse power per hour from less than one pound of coal.

While these gas engines are built both in vertical and horizontal type, we will describe below only a typical horizontal construction, the Koerting four-cycle engine, of which a longitudinal section is shown in Fig. 233.

Cycle.—In the well-known Beau de Rochas or four-stroke cycle on which this engine operates, three strokes of the piston are employed for the purpose of expelling the burned gases, drawing in the fresh charge of combustible mixture of gas and air and, by forcing it under high pressure into the small space afforded by the combustion chamber, preparing it to do work on the succeeding or fourth stroke.

Expansion.—In the illustration shown, the piston has advanced about half way on its power stroke. Ignition of the combustible charge effected by a special mechanism described below under that head, having taken place just before the crank passes the dead center, the high-pressure gas, expanding after having received the heat generated by its own combustion, transforms the heat into work, which, transmitted through the piston and connecting rod, turns the main engine shaft.

Exhaust.—Just before the engine passes the outer dead center the exhaust valve shown at the bottom of the cylinder head is opened and the pressure at once drops to that of the atmosphere. This exhaust valve remains open during the return stroke and allows

the burned gases to be expelled by the returning piston. The hot gases escaping through the valve opening are cooled by water surrounding the valve housing and exhaust pipe, which reduces the back pressure and tends to silence the exhaust.

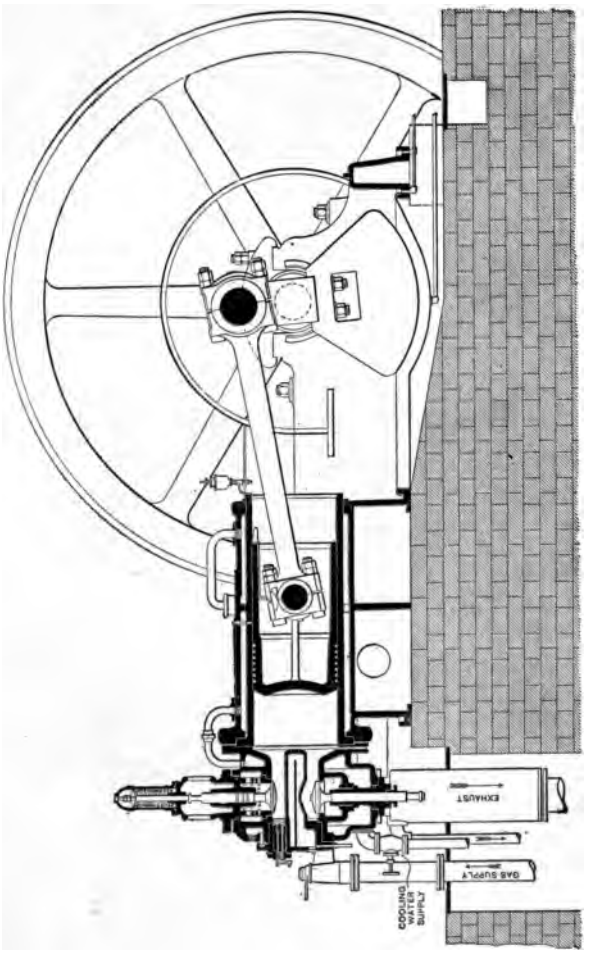


FIG. 233. LONGITUDINAL SECTION OF FOUR-CYCLE GAS ENGINE.

Fresh Charge.—As the piston starts on its second out-stroke the exhaust valve is closed and the admission valve is opened, allowing the piston to suck in a fresh charge of gas and air accurately proportioned—by passing through an outside set valve—to conform to the requirements of perfect combustion and maximum economy.

Compression.—On the return stroke both the admission and the

exhaust valve are closed, and the charge thus trapped in the cylinder is compressed by the returning piston to the volume of the clearance spaces afforded in the end of the cylinder and the combustion chamber.

During compression the temperature of the charge rises very

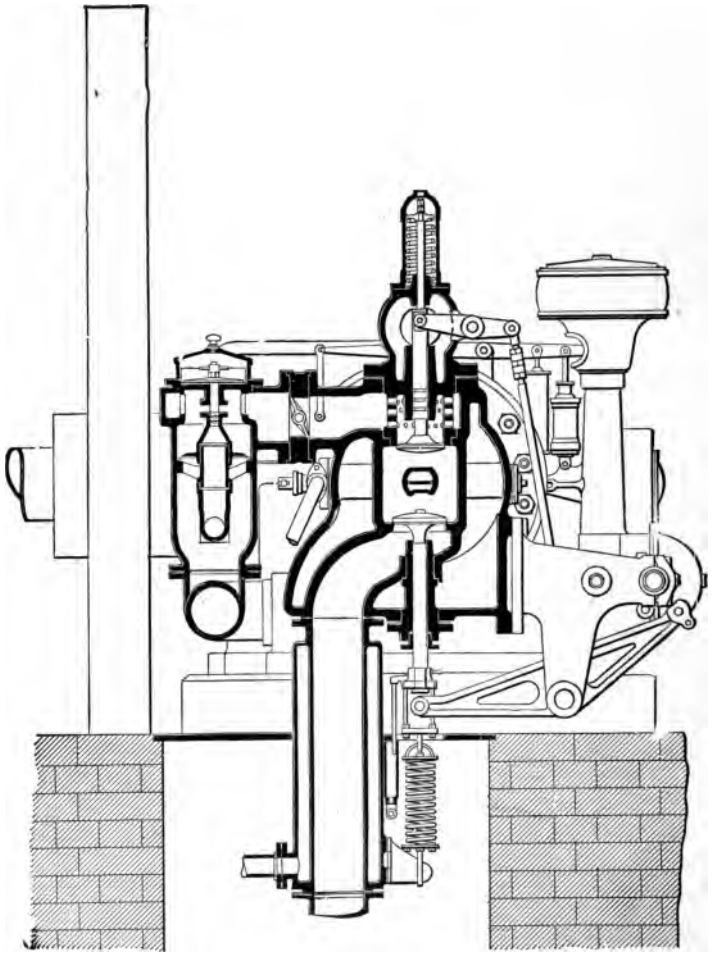


FIG. 234. TRANSVERSE SECTION OF FOUR-CYCLE GAS ENGINE.

rapidly and the limit at which the compressed charge will ignite from its own heat is soon reached.

Since in gas engine practice the economy attained depends upon the degree of compression of the charge prior to ignition, modern

practice demands that compression be carried as high as this ignition temperature will admit.

Rich gases, or those contaning large quantities of hydrogen and hydrocarbons, ignite at a lower temperature than "leaner" gases, in which the percentages of these constituents are lower. As the size of the engines increases the cylinder jacket becomes less effective in cooling the central part of the mass of mixture. The evil effect of these conditions, which tend to produce preignition, is kept within bounds by a new system of jackets, through which cold water is circulated. This reduces the temperature of the charge, so that the comparatively high compression, necessary to high economy, is made possible. In order, then, to employ rich gases to their best advantage in medium and large size engines, the Koerting engine is provided with a specially designed internal water jacket, the cooling surface of which may be increased to meet the demand made by gas of any composition working in an engine of any size. This device consists of a hollow water-cooled cover secured to the back of the cylinder head and projecting into the combustion chamber. By slightly changing the shape of this casting the cooling surface may be varied at will to suit any requirement. This simple device allows even the largest engines to enjoy the same high compression as is used in the smallest without fear of preignition.

The incoming gas having passed through a set regulating valve in the gas main is supplied to the mixing valve in the proper proportion to insure perfect combustion and consequent maximum efficiency.

Governing.—The combustible complement of air and gas mixed according to the requirements of perfect combustion, before being admitted to the power cylinder, is made to pass a throttling valve, which determines the amount of fuel necessary to maintain the required speed for one complete cycle.

Ignition is effected by an oscillating electromagnet which insures a spark of uniform strength regardless of the speed of the engine.

The transverse section of a Koerting engine is shown in Fig. 234. These engines are started by means of compressed air stored in a receiver.

For large units the four-cycle engines are built double acting, twin and tandem.

Suction Producer.—The type of producer which has been found

to be the best adapted to small and medium size installations is known as the suction producer to distinguish it from the form in which the gas is supplied to the engine under a slight pressure, and which is more complicated on account of involving the use of gas-holders, boilers and much additional piping. In this form of producer exterior atmospheric pressure is employed to force the combustible mixture of gas and air into the motor cylinder, a vacuum sufficient to overcome the resistance encountered by the gases in

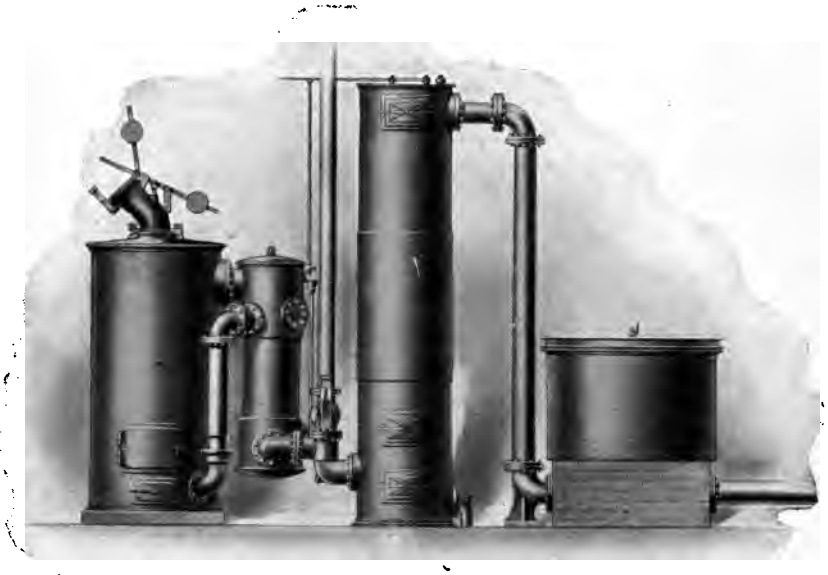


FIG. 235. GENERAL VIEW OF SUCTION PRODUCER.

traversing the generating apparatus being produced by the action of the motor piston itself.

In engines working on suction producers, regulation is effected by means of a balanced valve inserted in the main gas supply line and actuated by the governor. This device not only controls the operation of the engine, but also that of the producer. In running under light load the throttling device allows only a small amount of gas to enter the cylinder and the suction on the producer is light. When the load increases, however, the throttling is less marked and a greater amount of air is allowed to rush through the producer, effecting the generation of an increased supply of gas to meet the

demands made by the engine. The general construction of a Koerting producer of the suction type is shown in Fig. 235. The plant consists essentially of a generator or producer, an evaporator, a scrubber or purifier, and a sawdust purifier.

Fig. 236 shows the sectional view of a generator and scrubber.

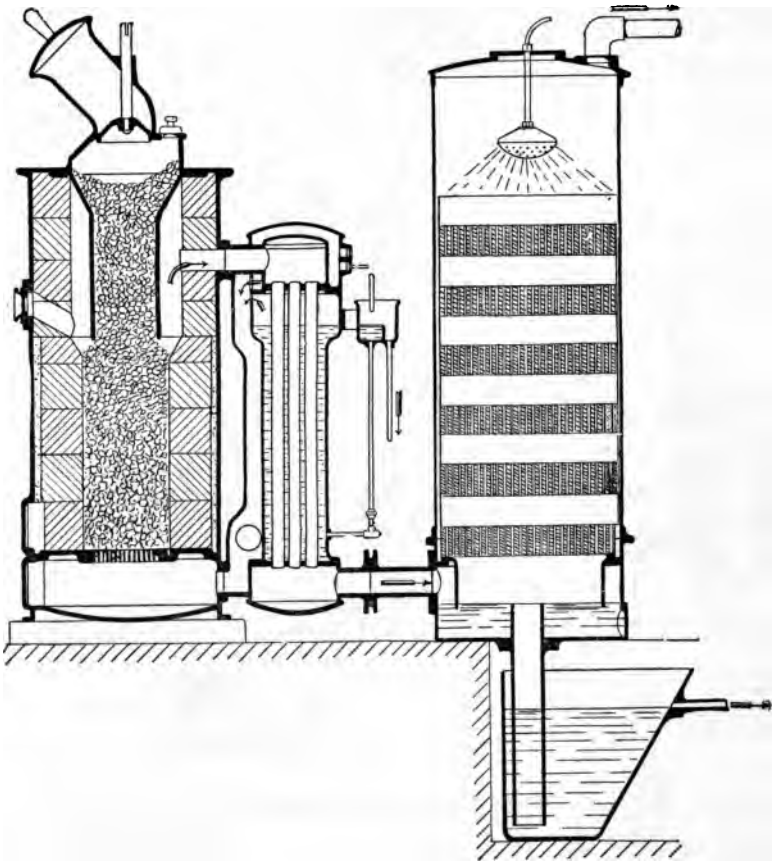


FIG. 236. SECTIONAL VIEW OF SUCTION PRODUCER.

Generator.—The generator is a vertical steel shell, cylindrical in form and lined with fire-brick. It is fitted at the bottom with grates similar to those in a vertical boiler and at the top with a hopper having an air lock through which coal is fed to the fire.

Evaporator.—At each charging stroke of the engine a quantity of air and gas is sucked out of the generator and passes through the evaporator. This device performs the double function of gen-

erating the steam and cooling the gases, and resembles in form a small tubular boiler. The gases, in passing down through the tubes of this boiler or evaporator, give up part of their heat to the water surrounding the tubes and evaporate sufficient steam to supply the generator. The water supplied to the evaporator passes, wherever it can be conveniently arranged, first through the water jacket of the engine, where it takes up considerable heat. In passing to the generator a fixed amount of air is allowed to be drawn in and mingled with the steam, thus supplying the oxygen necessary for the partial combustion of sufficient coal to maintain necessary generator temperatures.

By this arrangement it is obvious that the heat necessarily abstracted from the hot gas on the way to the engine, as well as that taken from the heated cylinder walls, is returned to the generator in the water and air with which it is supplied.

Scrubber.—The gases generated from ordinary fuels, especially from soft coal, are unfit, because of entrained impurities, to be used uncleansed within the cylinder of an engine. The amount and nature of these impurities naturally vary widely with the kind of fuel used, being nil for pure carbon.

The impurities to be removed from the gas generated from a ton of fuel are, for anthracite coal, from one or two pounds of ammonia, traces of sulphur and from five to ten pounds of tar, and from bituminous coal, from four to five pounds of ammonia, sulphur varying from "traces" to five per cent., and from ten to twelve gallons of tar.

In the case of suction producer plants using anthracite coal and carbonized fuels, such as charcoal and coke, the purifying process requires only a washer or scrubber. From the evaporator the cooled gas passes through a vent valve into the bottom of the scrubber and up through a bed of coke over which a spray of water is continuously running. While passing through this wet coke, the gas is further cooled and cleansed of any fine ash or foreign matter which it may have carried over from the generator.

Sawdust Purifier.—The gas leaving the scrubber descends through a vertical pipe and enters the sawdust purifier. Within the purifier it rises to the top through a short vertical pipe, and spreading over the entire cross-section of the cylindrical shell, filters down through two or more layers of sawdust supported on wooden gratings. The

size of this cylinder allows the gas to travel very slowly and any impurities, such as tar, moisture and dust, not separated out in the scrubber are caught in the sawdust beds.

The comparatively large volume of the purifier also constitutes a suction receiver which reduces the pulsating effect due to the suction of the engine and makes the pull on the generator practically constant.

Starting.—The plant is started by first building a fire on the grate of the generator and charging it with coke or coal, the chimney pipe being open and the engine gas pipe closed. Air is forced through the generator by means of a small hand blower until the charge is well ignited, the vent valve being turned so that the smoke will escape to the atmosphere through the chimney.

When a part of the gas is to be used for heating or other outside purposes, the blower or exhauster is placed in the gas main beyond the scrubber and so operated as to put the gas under sufficient pressure to force it through the pipes to the place of consumption. In this case the vent valve is placed behind the exhaust fan and arranged to divert the smoke into the chimney while starting up. The fuel having become incandescent up to the bottom of the hopper, the passage to the chimney is closed and the gas is tested by igniting a small jet from a test cock. If the gas burns with a reddish-blue flame not easily extinguished, the valve leading to the engine may be opened and the engine started. As soon as the engine has made a few revolutions it will pump its own gas, and unless the exhaust fan is required to force the gas through an outside system it can be stopped.

When the plant is to be shut down the generator is filled up with coal and the vent valve to the chimney opened to a mark which has been predetermined to admit the passage of just sufficient air to maintain a fire. Opening the vent valve to the chimney closes the communication with the scrubber and the gas which it contains can be used the next time the engine is started.

These producer plants consume only a very small amount of coal while the engine is shut down and are much more economical than boiler plants which, while the fires are banked and no power is being used, often consume ten per cent. or more of the amount of coal required for the performance of their rated capacity. The plant after being shut down can be put in operation at full capacity

in a few minutes and, on account of the heavy bed of burning coal carried at all times, meets the requirements of wide fluctuations in load with great promptness. In operating small plants it is necessary to charge coal through the hopper only about every two or three hours, shaking the fires to break up the bed of coal and remove ash, and inspection of the evaporator to see that it is properly supplied with water may be made more frequently. The removal of ashes from the water-sealed pit is performed two or three times per day.

Among the numerous advantages possessed by suction producers is their low first cost, extreme simplicity, and the fact that being operated under slight vacuum any leak will have the effect of drawing exterior air into the apparatus instead of allowing gas to escape to the outside, as may sometimes occur in the case of pressure producers not under the care of skilled attendants. The steam used in these producers, being drawn in by a slight vacuum produced by the engine itself, is never above atmospheric pressure and hence requires no boiler for holding steam under pressure to operate injectors as in the case of most pressure producer plants.

Pressure Producer.—On account of its unusual adaptability to varying conditions and fuels and ability to meet varying requirements of load, and because gas is easily piped to a distance without loss by condensation, the pressure producer, Fig. 237, may be employed in plants of over 75 horse power.

The chemical reactions involved in generating gas are practically the same for both the suction and the pressure producer, the essential difference between the two types being in their mode of operation. In the former case the gas is sucked from the generating apparatus by the action of the engine itself, and in the latter case steam and air are forced into the producer by a pressure blower using steam from a small auxiliary boiler. This blower not only supplies the power necessary to overcome the resistance encountered by the gas in passing through the generator and the cleaning apparatus on its way to the gas holder, but also introduces the steam, which through decomposition affords a means of controlling generator temperatures and by reducing the quantity of air used greatly increases the heat value of the resulting gas.

In the suction producer, steam is evaporated in a small evaporator at atmospheric pressure by the hot gases on their way to the scrub-

ber; in the pressure type the steam is generated at from 70 to 100 pounds pressure in an auxiliary boiler. The evaporator of the suction producer is replaced in the pressure producer by an economizer which effects a heat interchange between the hot gases leaving the generator and the air entering it. The economizer, like the

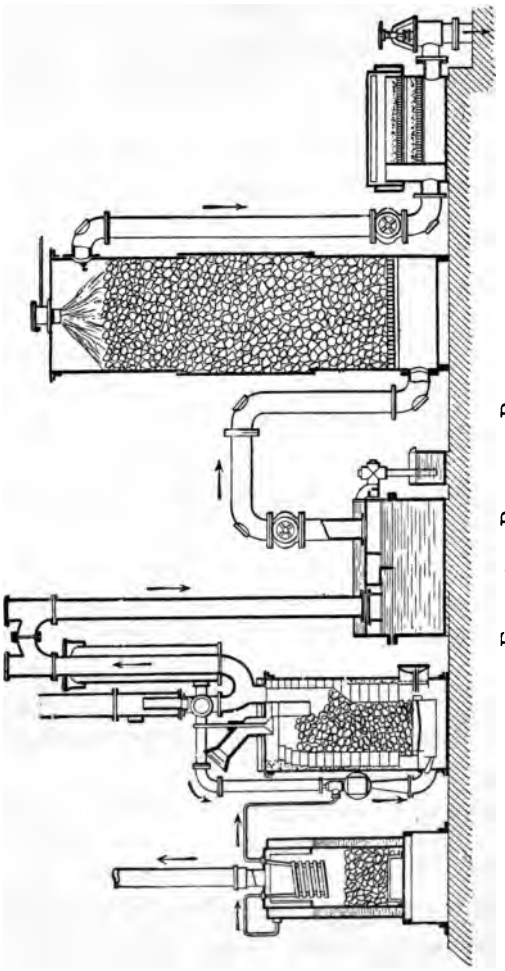


FIG. 237. PRESSURE PRODUCER.

evaporator, is similar in constrcution to a small tubular vertical boiler, and the gases pass through the tubes and the air around them.

While as yet anthracite coal is the only fuel that has proven entirely satisfactory in the suction producer, almost any fuel containing carbon and volatile hydrocarbons can be employed in the

pressure producer, and any of these gases capable of forming a combustible mixture with air can be employed for generating power in a properly designed gas engine.

The gasification of bituminous fuel requires, as I have explained in a previous chapter, a producer of different construction from the one used for anthracite, as in approaching the incandescent part of the fuel bed tar is liberated, so that in an ordinary producer only gas high in tar contents can be generated. These tarry substances, however, can be decomposed at high temperature into hydrogen, carbon dioxide and carbon monoxide. If the tarry gases are passed again through incandescent coal the tar is destroyed and at the same time utilized by its decomposition. The simplest way to do this is to connect two or more producers, one behind the other, so that for instance the gas generated in the first producer, which is charged with green coal is passed through the second producer which contains hard fuel or fuel out of which the bituminous parts have already been removed.

An example of such a producer combination is the producer plant of Jahns, which is used in Germany for gasifying a low-grade residuum of the coal mines containing about 25 per cent. combustible matter.

For ordinary fuels and small plants, however, this system is rather complicated; therefore a different producer construction has been devised in Germany for gasifying lignite briquettes, in which the gas outlet is provided near the grate. This producer works by down-draft and is charged from the top. The tarry gases go through the incandescent fuel, whereby the tar is converted into gas.

More perfect producer plants for bituminous fuels combine practically two producers into one, *i. e.*, the producer has two "burning layers," one on top and one on the bottom, the gas being removed between the two. The process in its first stage is similar to the common retort gas process; the upper layer corresponds to the retort; here the tarry matters are driven out and the fuel coked. In the lower layer the tar is fixed and the coke gasified. The operation is regulated by the quantity of air admitted to each one of the two burning layers. The gas leaving these producers is fairly cool, so that it is unnecessary to use an evaporator, while with a producer for anthracite or coke an evaporator of sufficient size is essential.

TABLES.

TABLE I. Producer Gas.

(Official test conducted at the coal-testing plant of the United States Geological Survey at the Louisiana Purchase Exposition, St. Louis, Mo., 1904.)

West Virginia Bituminous Coal.

Average Composition of Coal and Gas.

Coal.	Per Cent.	Gas by volume.	Per Cent.
Moisture	1.99	Carbon Di-oxide	10.16
Volatile Matter	28.89	Oxygen	.24
Fixed Carbon	60.30	Carbon Mon-oxide	15.82
Ash	8.82	Hydrogen	11.16
		Methane	3.74
Sulphur	.79	Nitrogen	58.88

Coal Consumed, Pounds Per Hour.

Coal consumed in producer	233
Dry coal consumed in producer	229
Combustible consumed in producer	208
Equivalent coal used by producer plant	262.8
Equivalent dry coal used by producer plant	258.2
Equivalent combustible used by producer plant	234.5

Gas Produced, Cubic Feet (Reduced to Standard).

Total	167,000
Per hour	18,560
Per pound coal consumed in producer	79.6
Per pound dry coal consumed in producer	81.2
Per pound combustible consumed in producer	89.2
Per pound equivalent coal used by producer plant	70.6
Per pound equivalent dry coal used by producer plant	71.9
Per pound equivalent combustible used by producer plant	79.2

British Thermal Units.

Per pound of coal	13,918
Per pound of dry coal	14,202
Per pound of combustible	15,600
Per cubic foot of standard gas	143.2
From standard gas per pound dry coal burned in producer	11,610
From standard gas per hour per brake horse power	11,320

Coal Consumed in Producer, Pounds Per Horse Power Per Hour.

	Coal as Fired.	Dry Coal.	Combustible.
Per electrical horse power available for outside purposes	1.23	1.21	1.10
Per electrical horse power developed at switchboard...	1.17	1.15	1.04
Per brake horse power[1] available for outside purposes..	1.05	1.03	.935
Per brake horse power[1] developed at engine.....	.992	.975	.885
Equivalent pounds used by producer plant per electrical horse power available for outside purposes.....	1.39	1.36	1.24
Equivalent pounds used by producer plant per electrical horse power developed at switchboard.....	1.32	1.29	1.17
Equivalent pounds used by producer plant per brake horse power[1] available for outside purposes.....	1.18	1.16	1.05
Equivalent pounds used by producer plant per brake horse power[1] developed at engine.....	1.12	1.10	.998

Horse Power Developed.

Average electrical horse power available for outside purposes.....	189.2
Average electrical horse power developed at switchboard.....	199.7
Average brake horse power[1] available for outside purposes.....	222.5
Average brake horse power[1] developed at engine.....	235

[1] Based on an assumed efficiency of 85 per cent. for generator and belt.

TABLE II. COMPARATIVE DATA OF STEAM AND GAS PLANT TESTS.

(Page 119 Preliminary Report of Coal Testing Plant of United States Geological Survey, St. Louis, 1904.)

Name of Sample.	B.T.U. per Pound Coal.	Per Cent. Combustible.	Duration of Trial.		Total Dry Coal Consumed per Hour.[1]		Dry Coal Burned per Square Foot of Grate Surface per Hour.		Water Evaporated from and at 212° F. per Pound of Dry Coal.	B.T.U. per Pound of Dry Coal Used.		Electrical Horse Power Delivered to Switch Board.		Total Dry Coal per Electrical Horse Power per Hour.[1]	
			Steam Plant.	Gas-producer Plant.	Steam Plant.	Gas-producer Plant.	Steam Plant.	Gas-producer Plant.[2]	Steam Plant.	Steam Plant.	Gas-producer Plant.	Steam Plant.	Gas-producer Plant.	Steam Plant.	Gas-producer Plant.
			Hours.	Hours.	Pounds.	Pounds.	Pounds.	Pounds.	Pounds.					Pounds.	Pounds.
Alabama No. 2	12,865	87	10.02	43.00	874	328.7	21.54	7.78	8.55	12,555	13,365	213.7	200.6	4.08	1.64
Colorado No. 1	9,767	74	9.97	30.00	722	341.7	17.80	7.56	7.21	12,577	12,245	149.1	200.2	4.84	1.71
Illinois No. 3	12,046	82	10.13	30.00	861	356.7	21.23	8.41	8.04	12,857	13,041	198.1	199.6	4.34	1.79[3]
Illinois No. 4	11,237	88	10.02	30.00	938	348.5	23.13	7.96	7.27	12,459	12,834	195.4	198.4	4.80	1.76[3]
Indiana No. 1	11,534	78	9.93	29.67	908	384.3	22.39	9.08	8.45	13,377	13,037	220.0	199.9	4.13	1.93[3]
Indiana No. 2	11,822	81	10.13	7.00	832	312 0	20.51	7.13	8.02	12,452	12,953	191.0	201.0	4.35	1 55[3]
Indian Territory No. 1	12,787	86	9.75	31.00	778	374.0	19.17	8.95	8.64	12,834	13.455	192.3	204.0	4.04	1.83
Kentucky No. 3	12,283	84	10.07	30.00	882	381.2	21.75	8.92	8.27	13,036	13,226	208.9	200.5	4.22	1.91[3]
Missouri No. 2	10,505	73	9.98	4.33	1,014	339.6	25.00	7.96	7.08	11,500	11,882	205.6	198.6	4.93	1.71[3]
West Virginia No. 1	14,166	92	9.98	24.00	768	315.6	18.94	7.36	8.95	14,198	14,396	196.7	200.4	3.90	1.57
West Virginia No. 4	13,918	89	10.00	9.00	770	258.2	18.98	5.96	9.65	14,002	14,202	212.5	199.7	3.62	1.29
West Virginia No. 9	14,195	92	10.00	6.33	721	320.1	17.78	7.60	10.09	14,616	14,580	208.2	201.0	3.46	1.59
West Virginia No. 12	14,614	92	10.13	30.00	719	300.5	17.68	6.92	9.90	15,170	14,825	203.6	199.8	3.53	1.50[3]
Wyoming No. 2	9,650	70	9.95	30.00	1,075	416.5	26.51	9.50	5.92	10,897	10,656	182.0	201.2	3.90	2.07

[1] In gas-producer plant this includes the coal consumed in the producer and the coal equivalent of the steam used in operating the producer.

[2] Coal actually consumed in producer only.

[3] Gas-producer hopper leaked during these tests.

From the statement made in the report the above results were obtained from tests conducted with a view of "demonstrating the possibility of using these coals in a producer and *not* to show how efficiently they could be burned. There is no question that in a second series of tests, the cost of coal per horse power will, in the majority of cases, be much less," and it is evident that the above comparisons are not as favorable as they should be for the gas engine.

TABLE III. THERMAL AND CHEMICAL DATA REGARDING COMBUSTION.

Gas.	Chemical Reaction.	Weight of Gas per cu. ft. 32° (Smithsonian T.).	Vol. in cu. ft. of 1 lb. Gas at Atmos. Pres.		Cu. ft. to Burn 1 cu. ft. of Gas. Gill.		Pounds to Burn 1 lb. of Gas.		Specific Heat of Gas at Const. P.	Heat of Combustion (Thompson).		
			32°	62°	O	Air.	O	Air.		Calories per cu. meter of Gas.	B.T.U. per lb. of Gas.	B.T.U. per cu. ft. of Gas.
Oxygen	23 lbs. O+77 lbs. N=100 lbs. air	.08927	11.20	11.88	...	.....	...	.....	.2175	.....	.....	.....
Nitrogen	21 vols. O+79 vols. N=100 vols. air	.07847	12.77	13.55	...	.....	...	.....	.2438	.....	.....	.....
Hydrogen	$2H+O=H_2O$	.00562	189.80	189.80	0.5	2.39	8	34.8	3.4062	3,062	61,524	344
Carbon	$C+O=CO$	.....	.....	.....	...	.....	...	.....	.....	.....	4,451	320
Carbon	$C+2O=CO_2$	.....	.....	.....	...	.....	...	.....	.....	.....	14,544	1,342
Carbon monoxide	$CO+O=CO_2$	.07704	12.77	13.55	0.5	2.39	.57	2.4	.2425	3,055	4,385	342
Carbon dioxide	1 lb. C+2.66 lbs. O=3.66 lbs. CO_2	.12323	8.12	8.60	...	.....	...	.....	.2072	.....	.....	.....
Methane marsh gas	$CH_4+4O=2H_2O+CO_2$	.04538	22.37	23.73	2.0	9.56	4.0	17.4	.5929	9,548	23,976	1,070
Ethylene, olefient gas	$C_2H_4+6O=2H_2O+2CO_2$	.07830	12.77	13.55	3.0	14.34	3.43	14.9	.4040	14,967	21,476	1,677
Ethane	$C_2H_6+7O=3H_2O+2CO_2$	.08369	11.94	.....	4.5	21.51	...	.....	.....	16,692	22,356	1,870
Benzole vapors	$C_6H_6+15O=3H_2O+6CO_2$	.27363	4.471	.....	7.5	35.85	...	.....	.3754	35,300	18,183	3,954
Acetylene	$C_2H_2+5O=H_2O+2CO_2$	.07251	13.79	.....	...	.....	...	.....	.....	13,881	21,421	1,554

The specific heat of a mixture of gases is equal to the sum of the products of the specific heat of each constituent gas by the percentage of that gas in the mixture divided by 100.

To convert calories per cubic meter in B.T.U. per cubic foot multiply by .1124.

To convert B.T.U. per cubic foot into calories per cubic meter multiply by 8.899.

To reduce volumes of air to pounds of air multiply by 12.39.

TABLE IV. Characteristics of Power Gases.

$H/(a'+1)$ B.T.U.'s per Cubic Foot Gas and per Cubic Foot of Mixture High and Low.

From Gas Engine Design—Lucke.

	H	CO	CH_4	C_2H_4	O	CO_2	N	Cu. ft. of Air per cu. ft of Gas.	Gas, B.T.U. per cu. ft.		Mixture, B.T.U. per cu. ft.	
									High.	Low.	High.	Low.
Natural gas	1.7	0.55	94.16	0.30	0.30	0.29	2.80	9.13	989	888	97.6	87.7
Cannel-coal gas	27.7	6.8	50.0	13.0	.....	0.1	2.4	6.50	843	762	98.2	85.7
Common-coal gas	39.78	7.04	45.16	6.38	0.06	1.08	0.50	6.38	727	651	98.5	83.1
Carburetted water-gas	21.8	28.1	30.7	12.9	0.5	3.8	2.2	6.00	702	635	100.3	90.7
Uncarburetted water-gas	49.50	35.93	1.05	.....	.....	4.25	8.75	2.10	295	265	92.2	82.8
Producer-gas, little steam	9.2	25.3	3.1	0.8	.....	3.4	58.2	1.24	160	150	75.0	67.0
Loomis Pettibone coal gas	14.0	20.0	2.0	0.20	0.10	8.2	55.5	.....	.....	.....	.....	.....
Dowson gas, average	18.0	25.0	3.0	.....	.....	7.0	47.0	1.32	119	115	51.4	49.6
Taylor gas, average	21.0	12.0	2.0	.....	3.0	6.0	57.0	0.98	130	116	65.5	59.0
Mond gas	29.0	12.0	2.0	.....	.....	14.5	42.5	1.17	156	139	71 9	64.0
Coke-oven gas	53.0	6.0	35.0	2.0	.....	2.0	2.0	5.06	620	524	102.3	86.4
Blast-furnace gas	3.0	27.5	.....	.....	.....	10.0	59.4	.81	100	99	55.3	54.8

TABLE V. Calorific Value of Elementary Gases.

J. Thompson—From Gas Engine Design—Lucke.

Fuel.	B.T.U. per Pound.		Pounds per cu. ft. at 62° F.	B.T.U. per cu. ft.	
	High.	Low.		High.	Low.
H	61524.0	51804.0	.00538	331.0	278.7
CO	4395.6	4395.6	.07498	329.58	329.58
CH_4	24021.0	21592.8	.04308	1037.22	932.38
C_2H_4	21222.0	19834.2	.07631	1619.45	1513.55

Volume of air per cubic foot gas is determined from the products and law of combination with oxygen to form these products. This volume of O found, when multiplied by 4.8, gives the air necessary on the assumption that 21 per cent. air is oxygen.

This gives: H—one cubic foot requires 2.4 cubic feet air.

CO " " " " 2.4 " " "

CH_4 " " " " 9.6 " " "

C_2H_4 " " " " 14.4 " " "

TABLE VI. Analyses and Calorific Values of Natural Gas from Different Localities.

From "Stirling" — by The Stirling Co. — Trinity Building, N. Y.

Location of Well.	Analysis by Volume.								Analysis by Weight.								Calculated Calorific Value in B.T.U. per 1,000 Cubic Feet of Gas.	Calculated Calorific Value in B.T.U. per lb. of Gas.
	H	CH_4	CO	CO_2	N	O	Heavy[1] Hydro-carbons.	H_2S	H	CH_4	CO	CO_2	N	O	Heavy Hydro-carbons.	H_2S		
Anderson, Indiana	1.86	93.07	0.73	0.26	3.02	0.42	0.47	0.15	0.22	91.00	1.18	0.70	5.14	0.82	0.82	0.32	1,016,900	22,030
Kokomo, "	1.42	94.16	0.55	0.29	2.80	0.30	0.30	0.18	0.17	91.90	0.93	0.75	4.78	0.58	0.51	0.37	1,021,850	22,040
Marion, "	1.20	93.16	0.60	0.30	3.42	0.55	0.15		0.15	90.50	1.01	0.91	5.80	1.06	0.26	0.41	1,008,760	21,680
Muncie, "	2.35	92.67	0.45	0.25	3.53	0.35	0.25	0.15	0.28	90.67	0.73	0.68	6.20	0.69	0.43	0.32	1,003,750	21,820
Bloomfield, New York	.....	82.41	.....	10.11	4.31	0.28	2.94		.....	67.00	.....	22.25	6.10	0.45	4.20	.....	925,550	16,820
Olean, "	.....	96.50	0.50	.....	.....	2.00	1.00		.....	93.90	0.75	.....	.....	3.75	1.60	.....	1,018,490	22,640
Findlay, Ohio	1.64	93.35	0.41	0.25	3.41	0.39	0.35		0.20	90.84	0.69	0.67	5.83	0.76	0.60	0.41	1,010,580	21,830
Fostoria, "	1.89	92.84	0.55	0.20	3.82	0.35	0.20	0.15	0.23	90.47	0.94	0.69	6.50	0.52	0.34	0.31	100,900	21,730
St. Mary's, Ohio	1.94	93.85	0.44	0.23	2.98	0.35	0.20	0.21	0.24	91.73	0.76	0.62	5.20	0.68	0.34	0.43	1,019,720	21,980
Barnes Well, near St. Ive, Butler Co., Pa.	6.10	75.54	trace	0.34	.....	.....	18.12		0.70	69.15	trace	0.85	.....	.....	28.30	.....	1,117,100	22,850
Cherry Tree, Indiana Co., Pa.	22.50	60.27		2.28	7.32	0.83	6.80		3.26	62.70	.....	6.52	13.40	1.72	12.40	.....	841,500	19,270
Grapeville, Westmoreland Co., Pa.	7.05	35.08	0.22	0.58	27.87	0.16	29.04		0.63	25.50	0.27	1.16	35.50	0.24	36.70	.....	892,950	14,270
" " " "	24.56	14.93	trace	trace	18.69	1.22	40.60		2.47	12.00	trace	trace	26.10	2.00	57.30	.....	924,500	16,460
Harvey Well, Butler Co., Pa.	13.50	80.00	trace	0.66	.....	.....	5.72		1.83	86.50	trace	1.95	.....	.....	10.80	.....	997,500	23,800
Leechburg, Westmoreland Co., Pa.	4.79	89.65	0.26	0.35	.....	.....	4.39		0.60	90.29	0.44	0.97	.....	.....	7.70	.....	1,046,380	23,380
Pittsburg, Pa.	9.64	57.85	1.00	.....	23.41	2.10	6.00		0.86	41.50	1.25	.....	45.94	3.00	7.45	.....	747,520	12,000
" "	14.45	75.16	0.30	0.30	2.89	1.20	5.40		2.09	83.09	0.58	0.91	0.50	2.43	10.40	.....	947,730	23,250
" "	20.02	72.18	1.00	0.80	.....	1.10	4.30		2.83	81.50	1.97	2.60	.....	2.60	8.50	.....	916,620	22,840
" "	26.16	65.25	0.80	0.60	.....	0 80	6.30		3.88	77.50	1.66	1.96	.....	1.90	13.10	.....	898,730	23,310
" "	20.03	60.70	0.58	.....	.....	0.78	8.90		4.40	73.50	1.24	.....	.....	1.96	18.90	.....	902,000	23,900
" "	35.92	49.58	0.40	0.40	.....	0.80	12.90		5.60	61.95	0.88	1.37	.....	2.00	28.20	.....	892,370	23,620
" "	22.00	67.00	0.60	0.60	3.00	0.80	6.00		3.40	83.20	1.30	2.10	6.60	2.10	1.30	.....	895,050	22,030
Caspian region, Russia	.....	92.24	.....	3.50	.....	.....	4.26		.....	84.52	.....	8.60	.....	.....	6.88	.....	1,062,000	21,570
" " "	.....	97.54	.....	2.47	.....	.....	.....	.....	.....	93.35	.....	6.65	.....	.....	.....	.....	1,050,000	22,200
" " "	.....	95.56	.....	4.44	.....	.....	.....	.....	.....	88.00	.....	12.00	.....	.....	.....	.....	1,030,000	20,900
Asperon Peninsula, Russia	0.34	92.49	.....	0 93	2.13	.....	4.11	.....	0.04	87.38	.....	2.43	3.35	.....	6.80	.....	1,061,670	22,280
" " "	0.98	93.09	.....	2.18	0.49	.....	3.26	.....	0.16	88.14	.....	5.55	0.83	.....	5.32	.....	1,063,360	22,170
Pechelbronn, Germany	.....	77.03	3.50	3.60	8.90	1.80	4.80	.....	.....	64.00	5.00	8.20	12.90	3.00	6.90	.....	908,200	16,900

[1] The calorific values given in the table are approximate only, as gases of the series CnHn + 2 are combined under the heading "Heavy Hydrocarbons." In making the calculations the calorific value of ethylene has been assumed as equal to that of the heavy hydrocarbons, since the bulk of the latter consists of ethylene.

TABLE VII. CONVERSION FACTORS—LINEAL.

Millimeter.....	1	10	25.4	304.8	914.4	1,000.0	.....	.....	.....
Centimeter.....	.1	1	2.54	30.48	91.44	100.00	.....	....	.....
Inch.....	.03937	.39370	1	12.00	36.00	39.37	39,370	63,360	72,960
Foot..	.00328	.03280	.08333	1	3.00	3.28083	3,280	5,280	6,080
Yard.	.00109	.01093	.02778	.33333	1	1.093611	1,093	1,760	2,026.66
Meter.....	.00100	.01000	.0254	.304801	.914402	1	1,000.0	1,609.35	1,853.19
Kilometer	.000001	.00001	.000025	.000315	.000914	.00100	1	1.60935	1.85319
Miles	.00000062	.0000062	.0000158	.000189	.000568	.000621	.62137	1	1.1515
Knots.....	.00000052	.0000052	.0000137	.0001645	.0004934	.00054	.53961	.8684	1

TABLE VIII. CONVERSION FACTORS—SURFACE.

Square millimeters	1	100	645.2	92,900	836,100	1,000,000
Square centimeters	.01	1	6.452	927	8,361	10,000
Square inches	.00155	.155	1	144	1,296	1,550.016
Square feet	.....	.001077	.00694	1	9	10.764
Square yards	.....	.00012	.00077	.11111	1	1.196
Square meters.....	.....	.0001	.000645	.0929	.836	1

TABLE IX. CONVERSION FACTORS—CUBICAL.

Cubic centimeters.....	1	16.387	1,000	3,785.4	28,315	764,552	1,000,000
Cubic inches.....	.061	1	61.023	231	1,728	46,656	61,023
Liters or cubic decimeters.....	.001	.016387	1	3.785	28.315	764.55	1,000
Gallons.....	.000264	.00433	.26417	1	7.48	201.97	264.17
Cubic feet.....	.000035	.000578	.035314	.13368	1	27	35.314
Cubic yards...	.0000013	.0000214	.001308	.00495	.037037	1	1.308
Cubic meters.	.0000010	.000016	.001000	.003785	.02832	.765	1

1 liter = 33.81 fl. ozs. 1 gal. = 128 fl. ozs. 1 qt. = 32 fl. ozs. 1 fl. oz. = 29.57 cu. cms.

TABLE X. Conversion Factors—Weight.

Grains	1	15.432	437.5	7,000	15,432.36	14,000,000	15,680,000
Grains	.064799	1	28.349	453.59	1,000	907,180	1,016,041.6
Ounces avoirdupois	.002280	.03527	1	16	35.274	32,000	35.840.0
Pounds avoirdupois	.000143	.002205	.0625	1	2.2046	2,000	2,240.0
Kilogram	.000064	.001	.02835	.45359	1	907.18	1,116.04

TABLE XI. Conversion Factors—Pressure.

Atmospheres	1	.06803	.03342	.02947	.001316	.0004726	.00009677
Pounds per sq. inch	14.7	1	.4913	.4332	.01934	.006947	.001423
Inches of mercury 32° F	29.922	2.036	1	.8818	.03937	.06414	.002895
Feet of water 60° F	33.94	2.309	1.134	1	.04464	.01603	.003283
Millimeters of mercury 32° F	760	51.7	25.398	22.399	1	.3592	.07355
Pounds per sq. foot	2,116	143.946	70.7	62.35	2.784	1	.2048
Kilograms per sq. meter	10,333	702.925	345.331	304.566	13.596	4.883	1

TABLE XII. Conversion Factors—Power.

Foot pounds per min.	1		44.2567	60	433.980				33,000.	44,256.7
Kg.—meters per min.		1	6.11872	8.29532	60				4,562.42	6,118.7
Watts	.0225954	0.163433	1	1.35573	9.805	7.5816	31.6469	69.7696	745.650	1,000
Foot pounds per sec			0.737612	1					550	737.612
Kg.—meters per sec			0.102979		1				76.040	101.979
B.T.U.'s per min			0.0568776			1			42.4108	56.8776
Lbs. Cent. per min.			0.0315987				1		23.5615	31.5987
Kg. — degrees Cent. large calories			0.0143329					1	10.6873	14.3329
Horse power			0.001341I	0.00181818	0.0131509	0.0235789	0.042442	0.093568	1	1.3411
Kilowatts			0.001	0.00135573	0.0098059	0.0175816	0.0316469	0.069769	0.74565	1

TABLE XIII. Conversion Factors—Heat Energy.

Joules	1	1.35573	9.80596	745.650	1,000	1,054.90
Foot pounds	0.737612	1	7.23300	550	737.612	778.104
Kilogram meters	0.101979	0.138255	1	76.0404	101.979	107.577
H.P. sec	0.001341	0.001818	0.0131509	1	.....	1.4147
K.W. sec	0.001	0.00135573	0.00980596	.....	1	1.0549
B.T.U	0.0009479	0.00128517	0.00929567	.....	.....	1
Pound Cent	0.0005266	0.000713986	0.00516426	.....	.....	.5555
Watt hour	0.00027777	0.000376591	0.00272388	0.207125	0.277778	.29302
Large calories	0.000238882	0.000323859	0.00234247	.....	.....	.25199
Horse-power hour	0	0.00000050505	0	.....	.....	.000392982
K.W. hour	0	0.000000376591	0.0000027238	.....	.....	.000293027

Joules	1,898.81	3,600	4,186.17	2,684,340	3,600,000
Foot pounds	1,400.59	2,655.4	3,087.77	1,980,000	2,655,403
Kilogram meters	193.639	367.123	426.900	273,745	367,123
H.P. sec	2.5465	4.828	5.61412	3,600	4,828
K.W. sec	1.8988	3.6	4.18617	.....	.....
B.T.U	1.8000	3.41266	3.96832	2,544.65	3,412.66
Pound Cent	1	3.89592	2.20462	1,413.69	1,895.92
Watt hour	0.52744	1	1.16282	745.650	1,000
Large calories	0.45359	0.859975	1	641.240	859.975
Horse-power hour	0.00070736	0.0013411	0.0015594	1	1.34111
K.W. hour	0.00052744	0.001	0.0011628	0.74565	1

Definition of Terms.

Joule = watt second = energy expended in one second by one standard ampere flowing through a resistance of one standard ohm.

Foot pound = 1 + 778 B.T.U.'s = energy expended by the force of one pound working through a distance of one foot.

Kilogram meter = 7.233 foot pounds = energy expended by the force of one kilogram working through a distance of one meter.

Horse-power = 33,000 foot pounds per minute = work done by 33,000 foot pounds of energy exerted in one minute = 550 foot pounds per second.

Kilowatt = 1,000 watts = kilowatt second = work at the rate of one joule per second.

B.T.U. (British Thermal Unit) = 778 + foot pounds = heat required to raise the temperature of one pound of water one degree F. at temperature maximum density 39° F.

Pound Centigrade = 1,400.59 foot pounds = heat required to raise the temperature of one pound of water one degree C. at temperature of maximum density 4° C.

Calorie — large — 3087.77 foot pounds = heat required to raise the temperature of kilogram of water one degree C. at temperature of maximum density 4° C.

Reactions Between Steam and Carbon.

Primary Reaction, 3. $\overset{I}{2C} + \overset{II}{O_2} = 2CO$ $24 + 32 = 56$ Producing Heat.	Reactions Decomposing Steam by Carbon.					
	5 $\overset{I}{H_2O} + \overset{I}{C} = \overset{I}{H_2} + \overset{I}{CO}$ $18 + 12 = 2 + 28$ Absorbing Heat.			6 $\overset{II}{2H_2O} + \overset{II}{C} = 2\overset{I}{H_2} + \overset{I}{CO_2}$ $36 + 12 = 4 + 44$ Absorbing Heat.		
Description of Processes.	Lbs. of H_2O	Lbs. of C to CO	B.T.U.	Lbs. of H_2O	Lbs. of C to CO_2	B.T.U.
Heat absorbed in decomposing steam at 212° F.	18	...	—104580	36	...	—209160
Heat absorbed in raising this steam from water, at 70° F.	18	...	— 19944	36	...	— 39888
Total heat absorbed in processes...	18	...	—124524	36	...	—249048
Heat developed by oxidation of C by O of the steam	...	12	+ 53400	...	12	+175776
Net heat absorption of processes ...	18	12	—71124	36	12	—73272
Heat deficiency per pound steam...	1	...	— 3951	1	...	— 2035
Heat produced per lb. of C burnt to CO by O of air blast by 3.....	...	1	4450	...	1	4450
One-third lost by radiation, etc.....	...	...	1483	...	...	1483
Heat available per lb. of C to meet deficiency in 5 or 6.....	...	...	2967	...	...	2967

In 5 steam oxidizes two-thirds and in 6 one-third of its weight in carbon.

In 5—Per lb. of C burnt by air the maximum steam decomposed = .75 lb. $\left(\frac{2967}{3951}\right)$

In 6—Per lb. of C burnt by air the maximum steam decomposed = 1.45 lb. $\left(\frac{2967}{2035}\right)$

Hence in

5—Per lb. of total carbon burnt by air and steam (1 + .5) it = .5 lb. steam.

6—Per lb. of total carbon burnt by air and steam (1 + .49) it = .98 lb. steam.

Quality of Gas with Varying Steam.

Gases, by Volume.	Excess of Steam.		
	Moderate.	Great.	Maximum.
CO_2	5.30 %	8.90 %	15.00 %
CO	23.50	16.40	11.50
CH_4	3.30	2.55	1.90
H	13.14	18.60	24.60
Heat value per cubic foot....	151 B.T.U.	135 B.T.U.	129 B.T.U.
Temperature	1472° F.	1292°	932° F.

Comparative Fuel Values.

Carbon.[1] Per Cent.	Percentage of Ash.												
	2%	3%	4%	5%	6%	7%	8%	9%	10%	11%	12%	13%	14%
75	.....	.....	.....	.....	.....	.....	$2.83	$2.82	$2.80	$2.79	$2.77	$2.76	$2.74
76	.....	.....	.....	.....	.....	.....	2.88	2.86	2.84	2.83	2.81	2.79	2.78
77	.....	.....	.....	.....	.....	$2.93	2.91	2.90	2.88	2.87	2.85	2.84	2.82
78	.....	.....	.....	.....	.....	2.97	2.95	2.93	2.90	2.88	2.86	2.84	.....
79	.....	.....	.....	.....	$3.01	2.99	2.97	2.96	2.94	2.92	2.90	2.88	.....
80	.....	.....	.....	.....	3.06	3.04	3.02	3.00	2.98	2.96	2.94	2.92	.....
81	.....	.....	.....	.....	3.10	3.08	3.06	3.04	3.02	3.00	2.98	.....	.....
82	.....	.....	.....	$3.17	3.15	3.13	3.10	3.08	3.06	3.04	3.02	.....	.....
83	.....	.....	.....	3.21	3.19	3.17	3.14	3.12	3.10	3.08	3.06	.....	.....
84	.....	.....	.....	3.25	3.23	3.21	3.18	3.16	3.14	3.12	.....	.....	.....
85	.....	.....	$3.33	3.31	3.29	3.26	3.23	3.20	3.18	.....	.....	.....	.....
86	.....	.....	3.37	3.35	3.33	3.30	3.27	3.24	.....	.....	.....	.....	.....
87	.....	.....	3.41	3.39	3.37	3.34	3.22	3.29	.....	.....	.....	.....	.....
88	.....	$3.46	3.44	3.42	3.39	3.36	3.33	.....	.....	.....	.....	.....	.....
89	.....	3.49	3.47	3.45	3.43	3.41	.....	.....	.....	.....	.....	.....	.....
90	$3.54	3.52	3.51	3.50	3.48	.....	.....	.....	.....	.....	.....	.....	.....
91	3.58	3.57	3.56	3.54	3.52	.....	.....	.....	.....	.....	.....	.....	.....
92	3.63	3.61	3.59	3.57	.....	.....	.....	.....	.....	.....	.....	.....	.....
98	3.68	3.66	3.64	3.61	.....	.....	.....	.....	.....	.....	.....	.....	.....

[1] Note.—The carbon and hydrogen are counted as carbon. Sulphur generally runs about one-tenth of the ash, but fuel containing over one per cent. of sulphur must not be used for making iron economically.

John M. Hartman.

Anthracite Coal Sizes.

Size and Name.	Through a Round Hole. Inches Diameter.	Over a Round Hole. Inches Diameter.
Broken		$2\frac{3}{4}$
Egg	$2\frac{3}{4}$	2
Stove	2	$1\frac{3}{8}$
Chestnut	$1\frac{3}{8}$	$\frac{3}{4}$
Pea	$\frac{3}{4}$	$\frac{1}{2}$
No. 1, Buckwheat	$\frac{1}{2}$	$\frac{1}{4}$
Rice	$\frac{1}{4}$	$\frac{1}{8}$

Losses Due to CO_2.

100 lbs. C Gasified with Air.	Pounds of C Burned to CO_2.					
Products.	0	5	10	15	25	50
CO per cent	34.4	31.5	29.5	26.6	22.7	12.9
CO_2 " "	.....	1.6	3.2	4.6	7.6	12.9
N " "	65.6	67.9	67.3	68.8	69.7	74.2
Pounds of gas	679	708	737	766	824	969
Cubic feet of gas	9,182	9,468	9,759	10,065	10,387	12,189
Per cent. of carbon energy in gas.	70	66	63	59	52	35
Heat units per cubic foot of gas..	109.7	100.5	94.1	85.8	72.04	41.1

CO_2 Formation with Dissociation of Steam.

Process.	Products.		
	Pounds.	Feet.	Per Cent. by Vol. (Approximate).
100 lbs. C burned to CO_2	366.66	3,153	25
70 per cent. of 1,450,000 heat-units is 1,015,000 units; which liberate from water H	16.34	3,110	25
130.96 lbs. O liberated from this water, combines with 49.2 lbs. C to form CO_2. This leaves 50.8 lbs. C to combine with 135.13 lbs. atmospheric O, which is associated with N	453	6,115	50
	836	12,378	100

Average Cost of Production of Sulphate of Ammonia.

Works of Brunner, Mond & Co., Ltd. (Northwich, England), for twelve months, ending March. 1899.

Items in Cost of Production.	Average Cost per Ton of Ammonium Sulphate for Twelve Months, Ending March, 1899.			
	£	s.	d.	American Equivalent.
Working producer and sulphate plant, gasifying an average of 4,650 tons of fuel per month	1	8	5.53	$6.930
Materials account — manufacturing	...	3	8.38	.900
Repairs — materials and labor	1	1	8.64	5.289
Acid used at 24 shillings per ton	1	3	6.18	5 726
Total cost of producing one ton of ammonium sulphate, the necessary steam being provided without charge from exhaust of steam or gas engines	3	17	4.73	18.845

Average monthly yield of ammonium sulphate ..... 180.2 tons
Average monthly amount of coal gasified ..... 4,650.0 tons
Average market value of ammonium sulphate in America during the last three years $64.960
Average cost of producing one ton of ammonium sulphate 18.845
Profit in producing one ton of ammonium sulphate $46.115

Note.—Where the gas is used in gas engines the heat of the exhaust gases from these engines will suffice to provide this steam at atmospheric pressure.

In steel works, chemical works, etc., there is usually waste steam available in abundance; where neither exhaust from steam nor gas engines is available, it has to be raised in special boilers.

USEFUL DATA.

Comparison of Producer and Illuminating Gas.

First-class carburetted water gas, made with 4½ gallons of Lima oil per 1,000 feet of gas, C.P. 26½; contains 730 H.U. per cubic foot.

One pound of anthracite coal (C 85 per cent., HC 5 per cent., ash 10 per cent.) will make about 90 cubic feet of gas of following composition.

CO 27 per cent., H 12 per cent., CH_4 1.2 per cent., CO_2 2.5 per cent., N 57 per cent.

This gas contains about 137 H.U. per cubic foot.

Therefore 17 cubic feet of carburetted water gas are equal in heat units to gas from one pound of anthracite.

1,000 feet C.W. gas equals gas from 59 + pounds anthracite.

Weight Per Cubic Foot of Coal and Coke.

	Lbs. per Cu. Ft.	Storage for Long Ton. Cu. Ft.
Anthacite coal, market sizes, loose	52–56	40–43
Anthracite coal, market sizes, moderately shaken	56–60	
Anthracite coal, market sizes, heaped bushel, loose	77–83	
Bituminious coal, broken, loose	47–52	43–48
Bituminious coal, moderately shaken	51–56	
Bituminous coal, heaped bushel	70–78	
Dry coke	23–32	80–97
Dry coke, heaped bushel (average 38)	35–42	

Standard bushel American Gas Light Association: 18½″ diam. and 8″ deep = 2,150.42 cu. in. A heaped bushel is the same plus a cone 19½″ diam. and 6″ high, or a total of 2,747.7 cu. in. An *ordinary* heaped bushel = 1¼ struck bushel = 2,688 cu. in. = 10 gallons dry measure.

Temperatures.

Degrees Fahrenheit = $\frac{9}{5}$ Degrees Centigrade + 32, or F.° = 1.8 C.° + 32.

Degrees Centigrade = $\frac{5}{9}$ (Degrees Fahrenheit − 32).

Degrees Absolute Temperature, T. = C.° + 273.

Degrees Absolute Temperature, T. = F.° + 459.4.

Absolute Zero = $\begin{cases} -273° \text{ on Centigrade Scale.} \\ -459.4° \text{ on Fahrenheit Scale.} \end{cases}$

Mercury remains liquid to − 39° C. and thermometers with compressed N above the column of mercury may be used for as high temperatures as 400° to 500° C.

Temperatures in Some Industrial Operations.

	Degrees. Centigrade.	Fahrenheit.
Gold[1]—Standard alloy pouring into molds	1180	2156
Annealing blanks for coinage, furnace chamber	890	1634
Silver—Standard alloy, pouring into molds	980	1796
Steel[2]—Bessemer process, six-ton converter:		
Bath of slag	1580	2876
Metal in ladle	1640	2984
Metal in ingot mold	1580	2876
Ingot in reheating furnace	1200	2192
Ingot under hammer	1080	1976
Siemen's open hearth furnace:		
Producer gas near gas generator	720	1328
Producer gas entering recuperator chamber	400	752
Producer gas leaving recuperator chamber	1200	2192
Air issuing from recuperator chamber	1000	1832
Products of combustion approaching chimney	300	590
End of melting pig charge	1420	2588
Completion of conversion	1500	2732
Pouring steel into ladle... beginning	1580	2876
Pouring steel into ladle... ending	1490	2714
In the molds	1520	2768
Siemen's crucible furnace:		
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Blast furnace on gray Bessemer:		
Opening in front of tuyere	1930	3506
Molten metal..... beginning to tap	1400	2552
Molten metal..... end of tap	1570	2858
Siemen's glass melting furnace:		
Temperature of furnace	1400	2552
Melted glass	1310	2390
Annealing bottles	585	1085
Furnace for hard porcelain, end of "baking"	1370	2498
Hoffman red brick kiln, burning temperature	1100	2012

Chemical Equations for Combustion in Oxygen.

HYDROGEN, H.

$$2H_2 + O_2 = 2H_2O.$$

Relation by volume—(2 vols.) + (1 vol.) = (2 vols.).

Relation by weight— 1 + 8 = 9

CARBON MONOXIDE, CO.

$$2CO + O_2 = 2CO_2.$$

Relation by volume—(2 vols.) + (1 vol.) = (2 vols.).

Relation by weight— 7 + 4 = 11

[1] W. C. Roberts-Austen.

[2] Professor Le Chatelier.

OLEFIANT GAS, C_2H_4.

$$C_2H_4 + 3O_2 = 2CO_2 + 2H_2O.$$

Relation by volume—(1 vol.) + (3 vols.) = (2 vols.) + (2 vols.).

Relation by weight— 7 + 24 = 22 + 9

MARSH GAS, CH_4.

$$CH_4 + 2O_2 = CO_2 + 2H_2O.$$

Relation by volume—(1 vol.) + (2 vols.) = (1 vol.) + (2 vols.).

Relation by weight— 4 + 16 = 11 + 9

1 cubic foot of Hydrogen at 32° F. and 14.7 lb. per sq. in. = .00599 lb. To find the weight of any other gas per cubic foot, multiply half its molecular weight by .00599.

HEATING VALUE OF SOME FUELS.

	B. T. U.
Peat, Irish, perfectly dried, ash 4 per cent	10,200
Peat, air-dried, 25 per cent. moisture, ash 4 per cent	7,400
Wood, perfectly dry, ash 2 per cent	7,800
Wood, 25 per cent. moisture	5,800
Tan bark, perfectly dry, 15 per cent. ash	6,100
Tan bark, 30 per cent. moisture	4,300
Straw, 10 per cent. moisture, ash 4 per cent	5,450
Straw, dry, ash 4 per cent	6,300
Lignites	10,000

The above are approximate figures, for on such materials qualities are very variable.

HEATS OF COMBUSTION OF VARIOUS SUBSTANCES IN OXYGEN.
(Favre & Silberman.)

One Part by Weight of	Burning to	Kilo-Calories Evolves.	B. T. U Evolves.
Hydrogen	H_2O at 0° C.	34,462	62,032
Hydrogen	H_2O at 100° C.	28,732	51,717
Carbon (wood charcoal)	CO_2	8,080	14,544
Carbon	CO	2,473	4,451
Carbon Monoxide	CO_2	2,403	4,325
Marsh Gas	CO_2 and H_2O	13,063	23,513
Olefiant Gas	CO_2 and H_2O	11,858	21,344

FORMULA FOR CALCULATING DIAMETERS OF PIPE.

Q = Discharge per hour; S = specific gravity of gas; h = pressure in inches of water; l = length of pipe in yds. D = Diameter of pipe. Then

$$D = \sqrt[5]{\frac{Q^2 S l}{(1350)^2 h}}$$

Ample margin should be allowed in calculations based upon this formula.

As far as the effect of heat is concerned, the volume of a gas varies as its absolute temperature. Its absolute temperature is the ordinary temperature + 273° on the Centigrade or + 460° in the Fahrenheit scale. Each

degree rise Centigrade increases the volume $\frac{1}{273}$ of its volume at 0° C., or of its volume at 32° F., approximately.

WEIGHT PER CORD AND COAL VALUE OF THOROUGHLY AIR-DRIED WOODS.

S. P. Sharpless.

Hickory or hard maple	4,500 lbs.	= 1,800 lbs. coal.
White oak	3,850 lbs.	= 1,540 lbs. coal.
Beech, red and black oak	3,250 lbs.	= 1,300 lbs. coal.
Popular, chestnut and elm	2,350 lbs.	= 940 lbs. coal.
Average pine	2,000 lbs.	= 800 lbs. coal.

SHIPPING TONNAGE.

U. S. Shipping Ton = 40 cu. ft.
= 32.143 U. S. bushels.
= 31.16 Imperial bushels.

British Shipping Ton = 42 cu. ft.
= 32.719 Imperial bushels.
= 33.75 U. S. bushels.

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Fig. 236, Sectional View of Suction Producer.
Fig. 237, Pressure Producer.

KOERTING
GAS PRODUCER BLOWER

The requirements to produce carbonic oxide gas from coal or other carbonaceous material are always met when the layer of fuel in the producer is sufficiently high to allow of the carbonic acid gas resulting from combustion on the grates being recarbonized in the upper portion of the fuel bank. **Under the most favorable conditions of altitude and temperature the strength of chimney-draft will not exceed two inches of water. To operate, therefore, a producer with this limited power corresponding conditions have to be created, involving a careful distribution of the fuel and a bank of very limited height.**

Another important consideration is that of distributing the gas to the points of combustion. When it is produced by natural draft, holders and other more or less expensive appliances must be provided to bring it under pressure, while with a pressure blast it is made and retained under pressure, and simply conducted by pipes to the point of combustion.

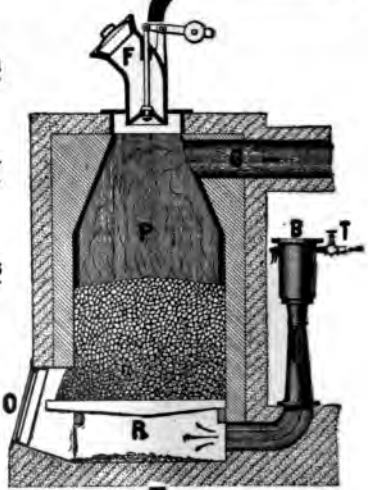
These Blowers have been especially constructed for application to gas producers and may be applied with great advantage where draft of from 3 to 4″ of water or more is required. They have no moving parts and require no driving machinery. They cannot get out of order.

Positive Operation

High Efficiency

No moving parts

Low Cost



Catalogue 4-A giving further information ; Price - List and table of capacities mailed on request

SCHUTTE & KOERTING COMPANY

12th & Thompson Sts., PHILADELPHIA, PA., U. S. A.

New York : 50 Church St.
***Boston*: 98 High St.**
Chicago : Security Bldg.
Pittsburg: Keenan Bldg.

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